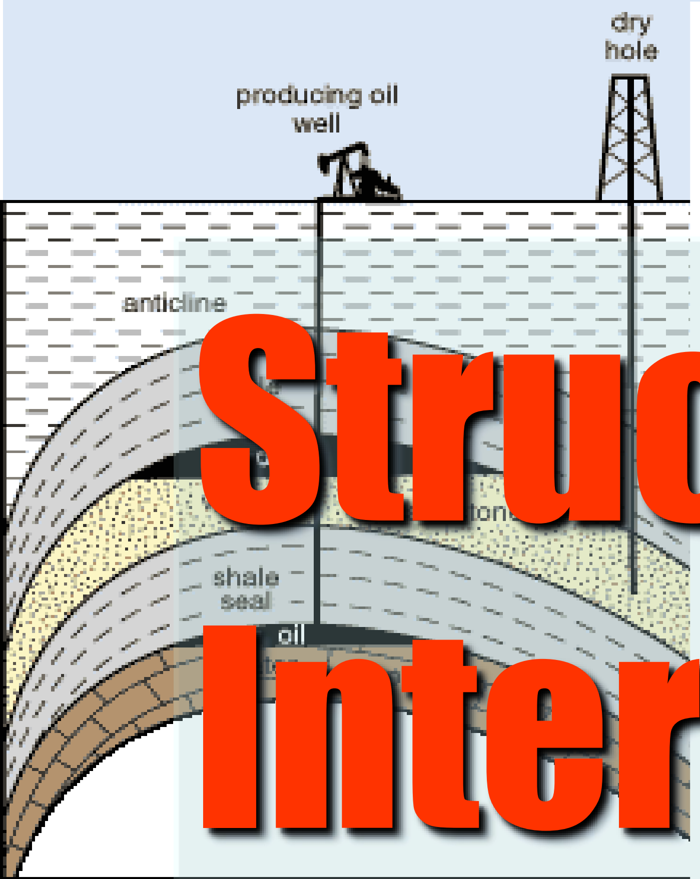
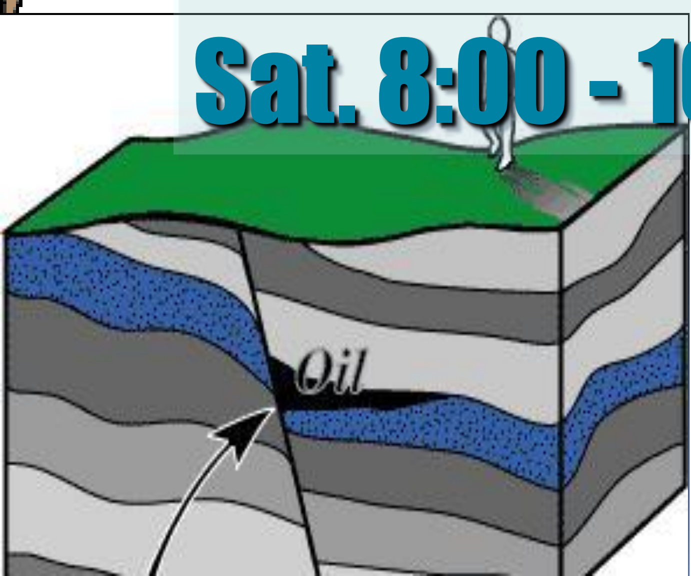
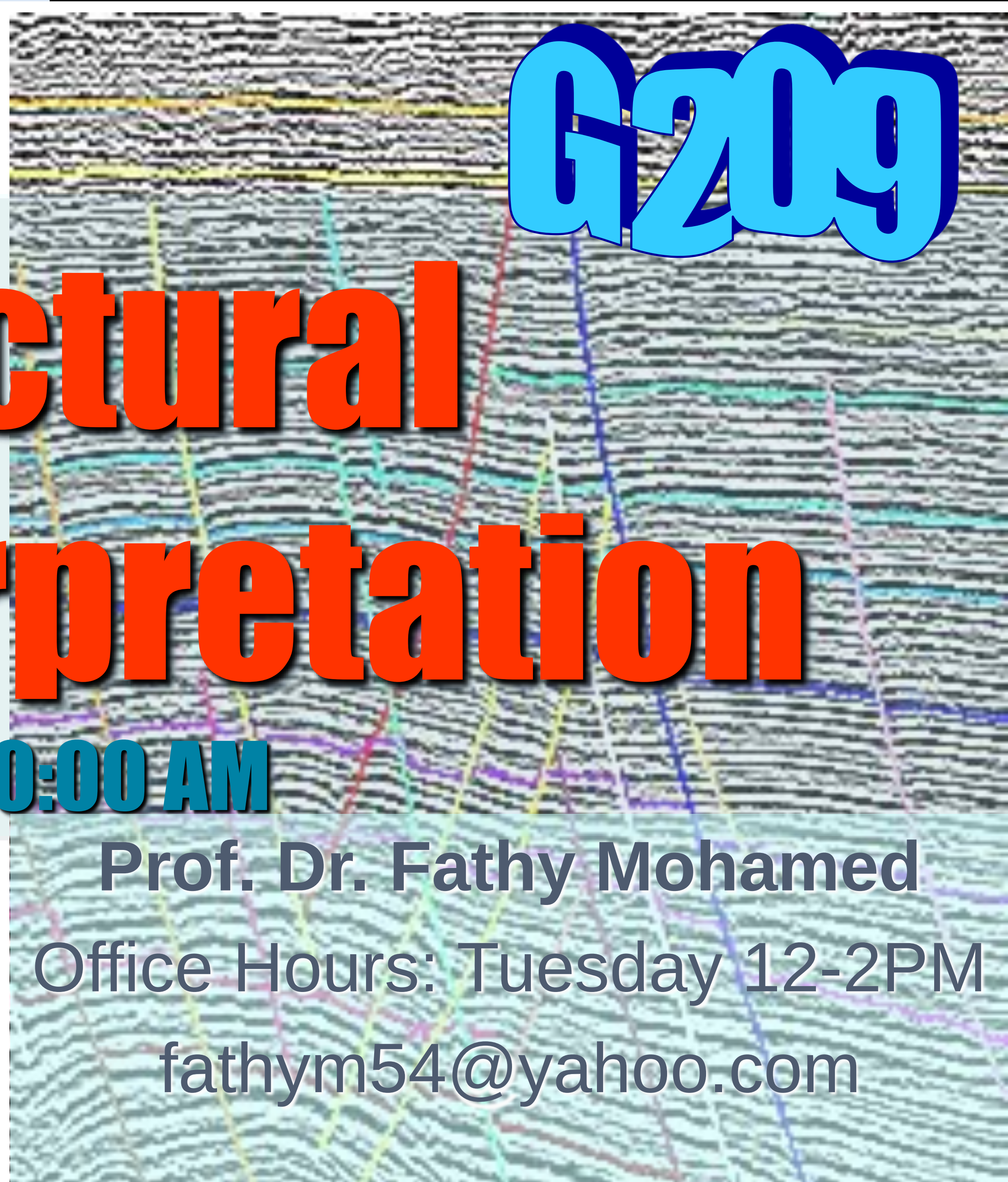
G209

Structural Interpretation

Sat. 8:00 - 10:00 AM







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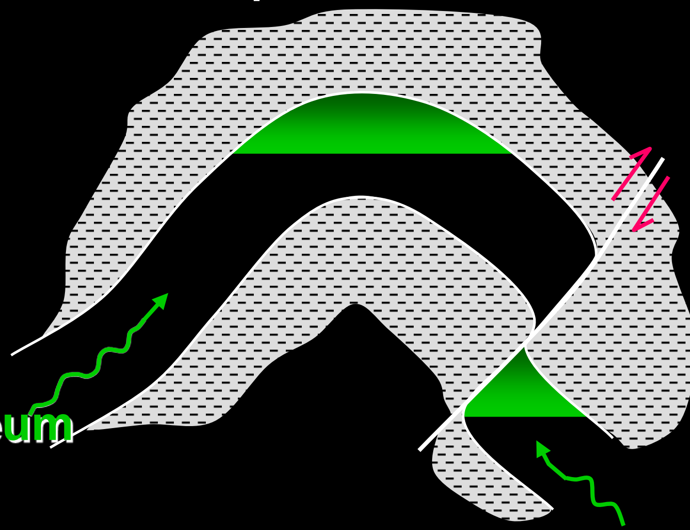
The Nature of Structural Geology

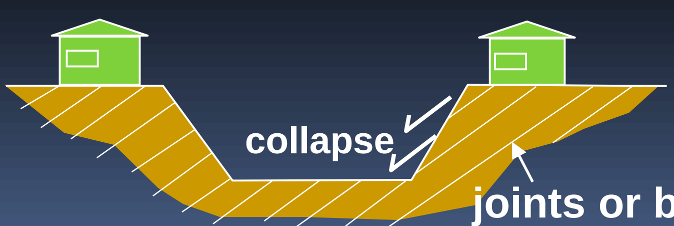
- Structural geology addresses the architecture of the Earth - the physical components or structures that make up the Earth’s crust, and that form in response to applied forces and stresses.
- An understanding of rock structures helps us interpret the Earth’s history and aids in economic ventures.
  - Oil exploration
  - Mineral deposits
  - Construction projects

Petroleum & Groundwater Exploration



Mineral Exploration

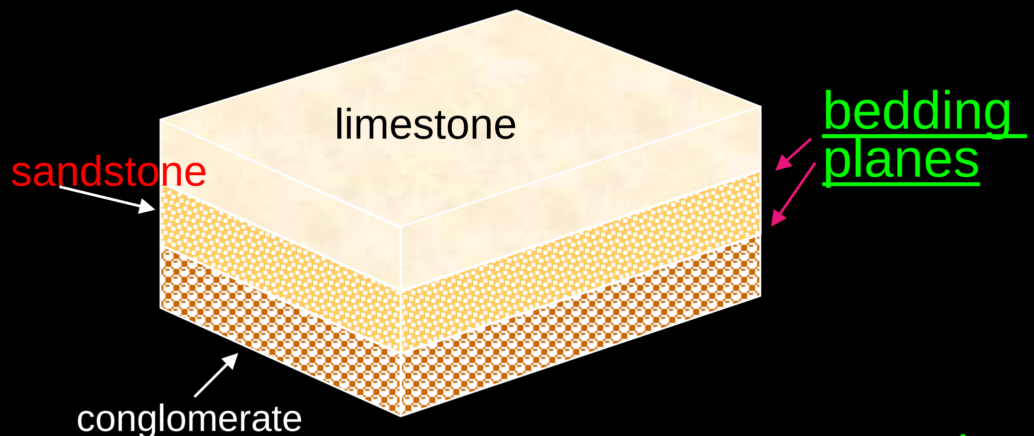
Engineering Geology

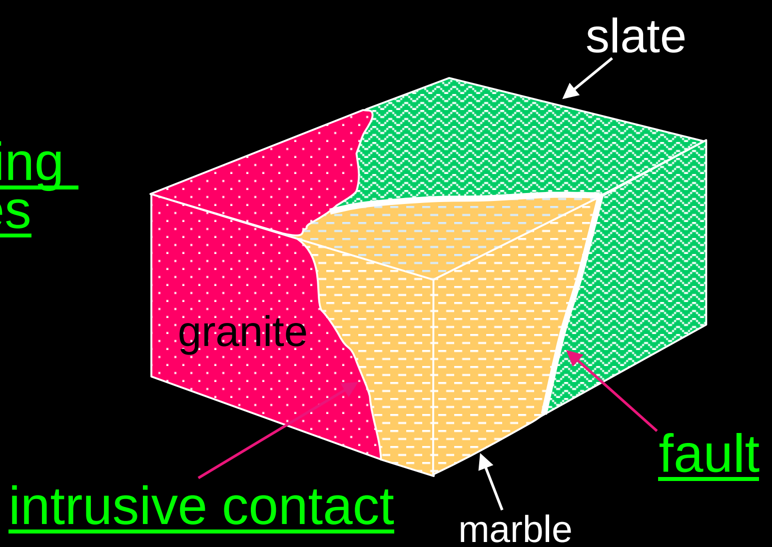


What are Geological Structures?

There are several types of structures. These include:

1. Geological Contacts





Bedding planes and igneous **intrusive contacts** have formed ***at the same time as the rocks*** we find them in. Structures formed at this time are called: **PRIMARY STRUCTURES**

Faults have formed ***after the rocks*** we find them in. Structures like these are called: **SECONDARY (OR TECTONIC) STRUCTURES**

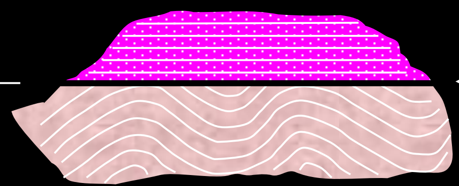
These are produced by rock deformation

Secondary Structures- Folding

So far we can see that geological contacts can be:

PRIMARY — sedimentary / igneous — or **SECONDARY**

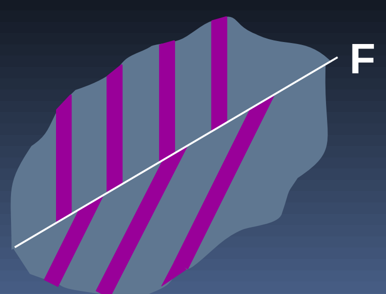
Another primary geological contact is an <u>unconformity</u>



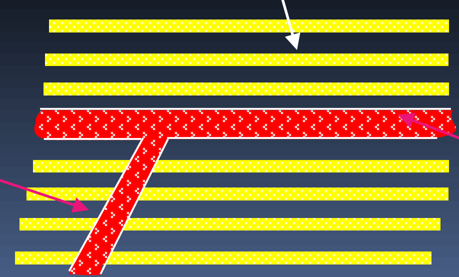
The beds below the unconformity often lie at an angle to the beds above. The beds above cross-cut the beds below. Any surface which *cross-cuts* or *terminates* or *interrupts* another is described as:

DISCORDANT

faults are often discordant



<u>dykes</u> are defined as discordant tabular intrusive bodies



CONCORDANT

structures are parallel to other surfaces e.g. the <u>sill</u> is concordant to beds

Dykes are Discordant Bodies and Faults are Cross –cutting (Discordant) Surfaces- Wadi Firan Sinai

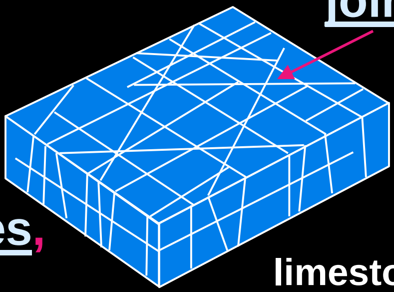
Faults are Cross –cutting (Discordant) Surfaces

Dykes are Discordant Bodies –Wadi Firan Sinai

Dykes are Discordant Bodies –Wadi Firan Sinai

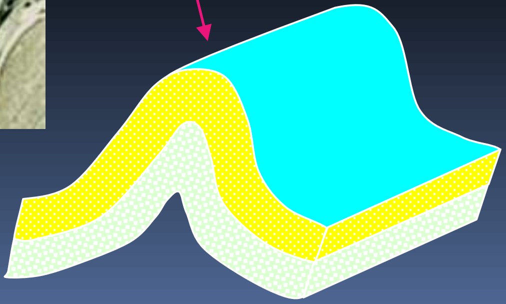
2. Discontinuities within rock bodies

The geological contacts enclose rock bodies. Within the rock bodies there may also be surfaces which divide the rocks into blocks. These surfaces are called *discontinuities*, and include joints, fractures, veins, etc.

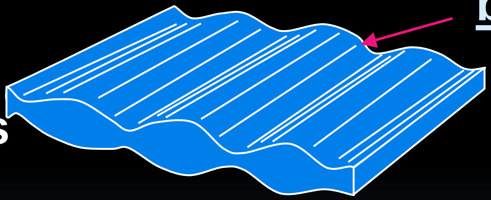


3. Shapes and features developed in 1. and 2.

folds are shapes defined by beds etc.



3-D shape of the boudins



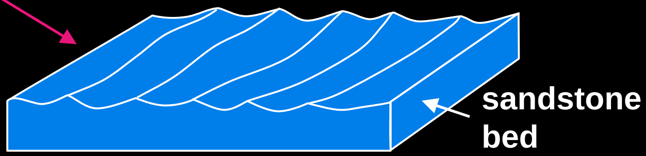
boudins are sausage-shaped structures in deformed veins

Boudins- Southern Sinai

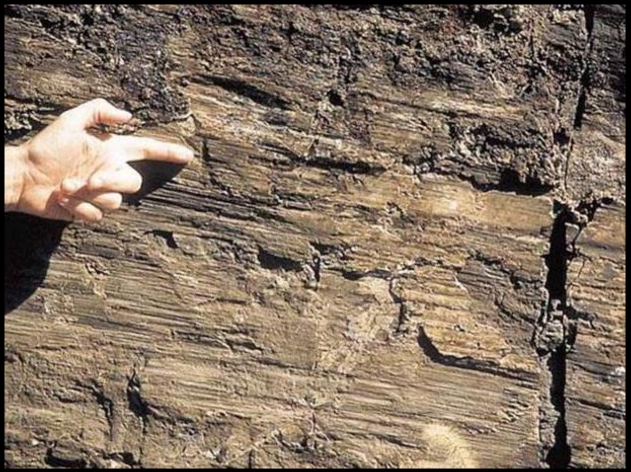
Boudins- Southern Sinai

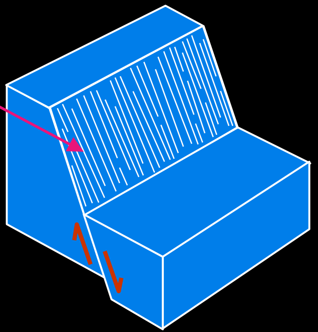
Rectangular boudins, formed by stretching of a granitic dike in metasediments. Cross-cutting relations are preserved between the dike margins and the foliation, showing that the dike rotated anticlockwise relative to the foliation. Hydrothermal deposition of quartz in the gaps between the boudins is a common feature in boudinaged felsic rocks. Photo: E. Rykkelid.

Features on surfaces are *linear*, e.g. ripple crests on bedding planes

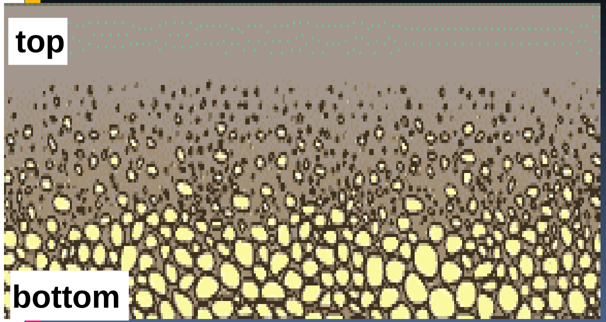


or striations (scratches) on fault planes

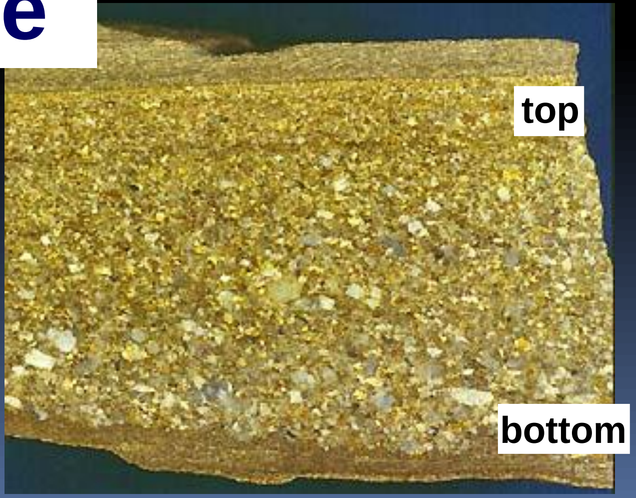


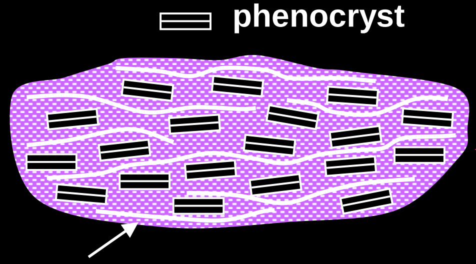


4. Patterns on the grain scale



Graded bedding is a *grain-size pattern* showing coarsest grains at the bottom of the bed and finest ones nearest the top of the bed

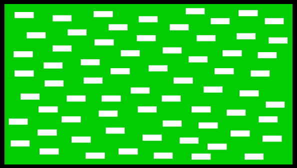




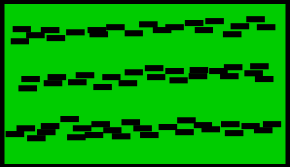
phenocrysts aligned by lava-flow (flow lineation) is an example of a *grain-orientation* pattern

Both graded bedding and flow lineations are primary structures

Mineral banding like gneissosity is an example of a *grain-distribution* pattern

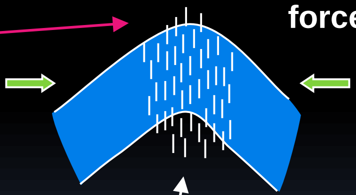


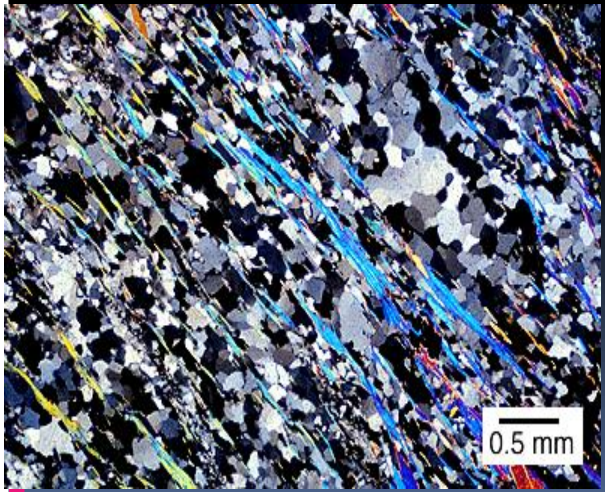
uniform distribution of mica grains



Gneissosity is a secondary (metamorphic) structure

cleavage is a secondary structure and is usually *discordant*





metamorphic mica flakes define cleavage

These grain patterns are usually small scale structures

Foliation and Lineation

Metamorphic foliation and lineation- Meatiq Dome- Eastern Desert

Metamorphic foliation and lineation- Meatiq Dome- Eastern Desert

Structures may be found on several scales. These are:

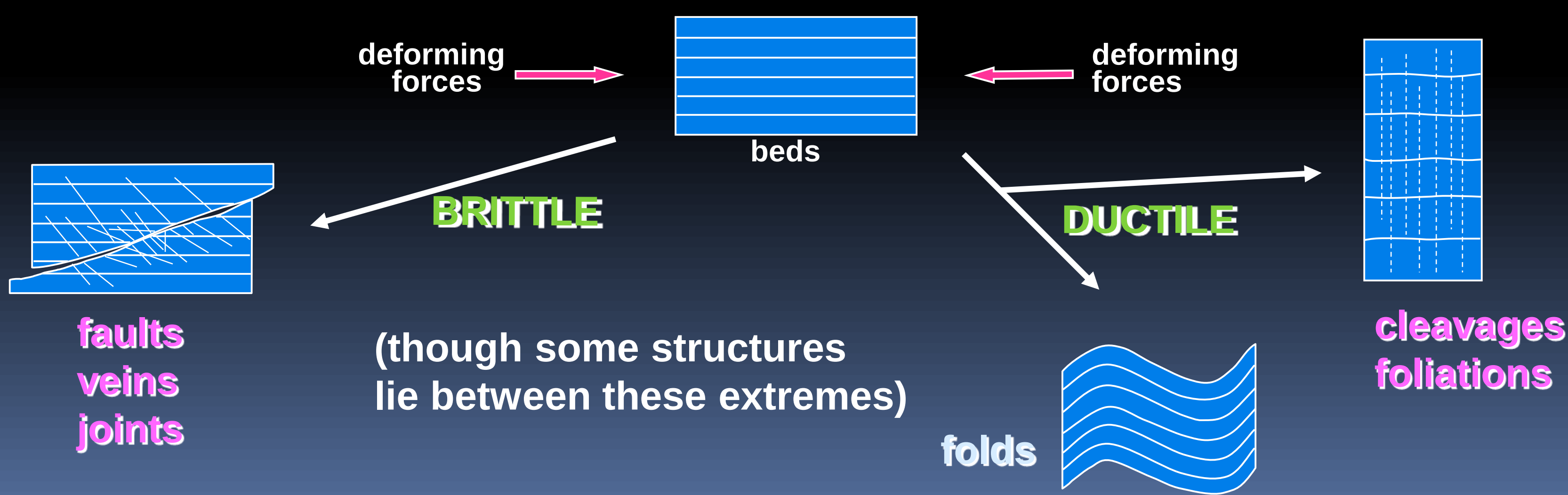
MICROSCOPIC → seen using a microscope

MESOSCOPIC → seen in outcrops or hand specimens

MACROSCOPIC → seen on maps or aerial photographs

Microstructures are also called *textures* by petrologists. The structures listed i 4 as a group may also be called *fabrics* (e.g. sedimentary fabrics, metamorphic fabrics, rock fabrics, petrofabrics etc)

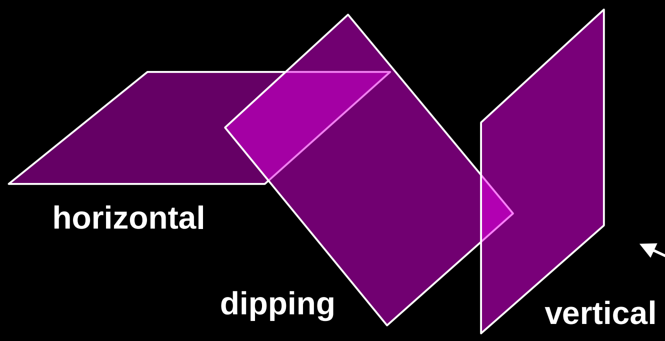
Structures may also be broadly divided into **BRITTLE** or **DUCTILE**

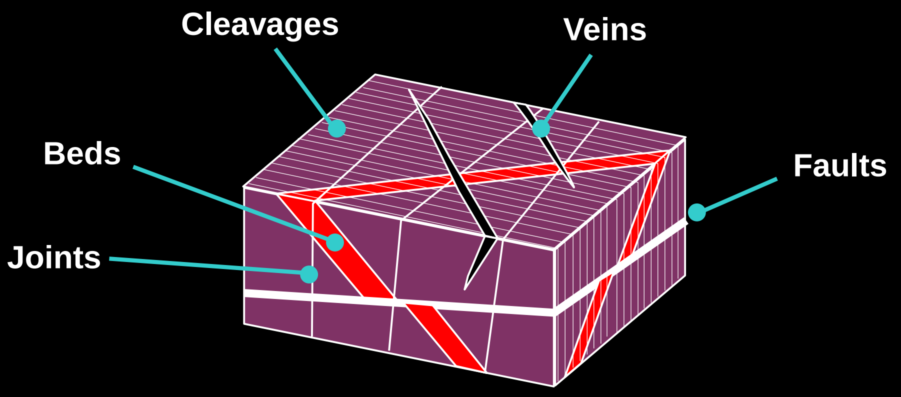


Folding is a Ductile Structure

Measurement of Planar and Linear Structures

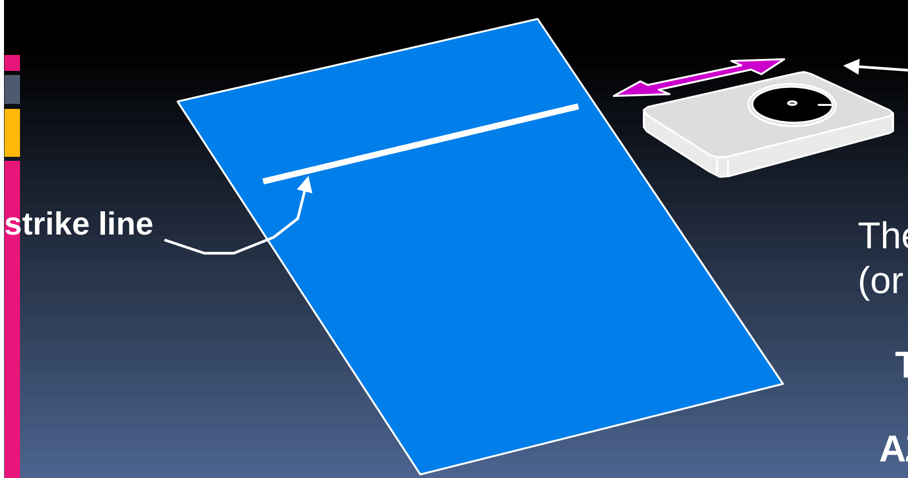
Many structures are essentially planar





These are the orientations of planes
How do we accurately measure these orientations?

Orientation of Planes



The compass direction of this line is called the STRIKE of the plane

The horizontal line in a dipping plane is called the strike line (or line of strike) of the plane

There are two ways to record compass directions:

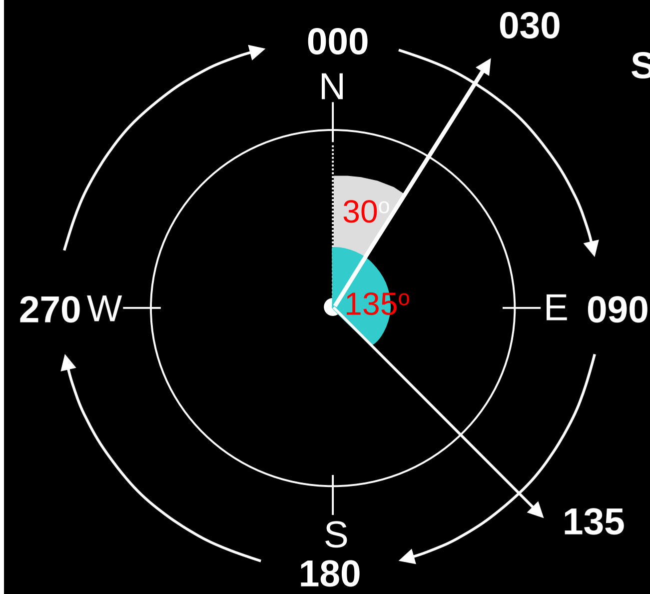
AZIMUTH

QUADRANT NOTATION

AZIMUTH

To represent a compass direction as an azimuth measurement we divide the compass into 360º beginning with zero at the North and counting clockwise

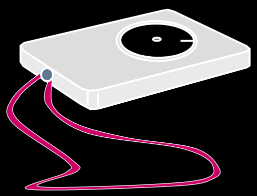
The azimuth directions are always three-digit numbers e.g. 005 025 130



So a direction 30º clockwise of North is referred to as 030

Opposite directions differ by 180º
e.g. NE and SW are opposite directions

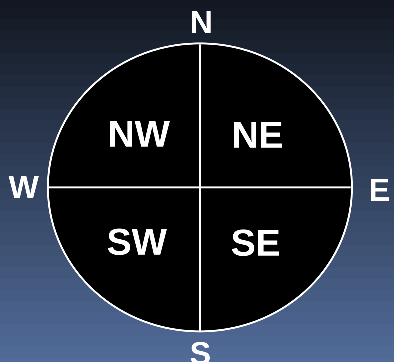
NE = 045 and SW = 225

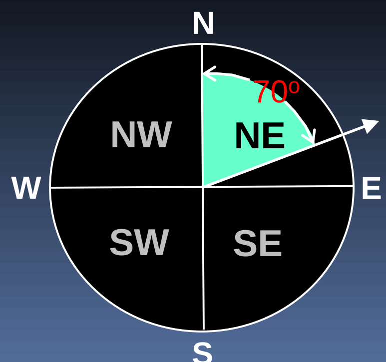


Southeast is referred to as 135

QUADRANT NOTATION

To represent a compass direction using quadrant notation we first divide the compass
four quadrants: the NE SE SW and NW quadrants





For any direction we first determine which quadrant it lies in

In this case it is the NE quadrant

In quadrant notation this direction will be written N ... E, whe
... represents the angle from N to the direction

In this example
the angle is 70º

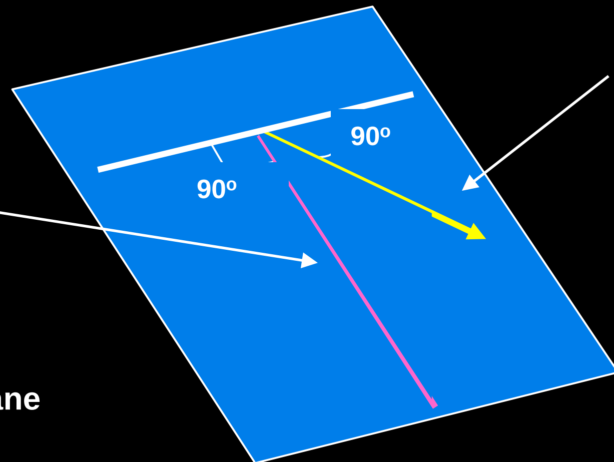
So this direction is written as N70E

After locating the strike line and measuring its compass direction, the next step is to find two other lines:

the <u>dip line</u> of the plane

which lies in the plane and 90º from the strike line

It is the steepest line in the plane



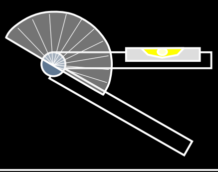
the <u>dip direction</u> of the plane

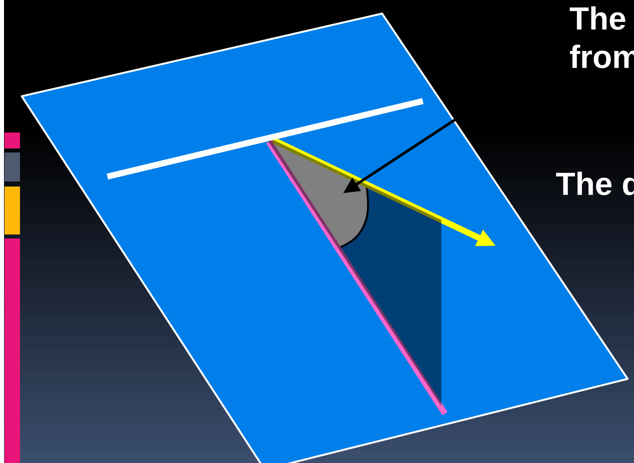
which is also at 90º to the strike line, but is a horizontal line pointing in the direction of the dip

Together these two lines define a vertical plane

The dip line is used to measure the angle of DIP of the plane

a clinometer is used to measure these angles



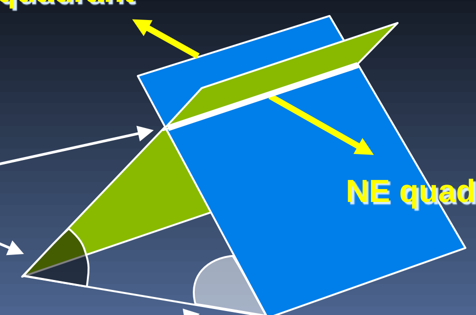


The dip is measured in this vertical plane from the dip direction down to the dip line

The dip is always less than or equal to 90º

The dip direction is normally only recorded as a quadrant

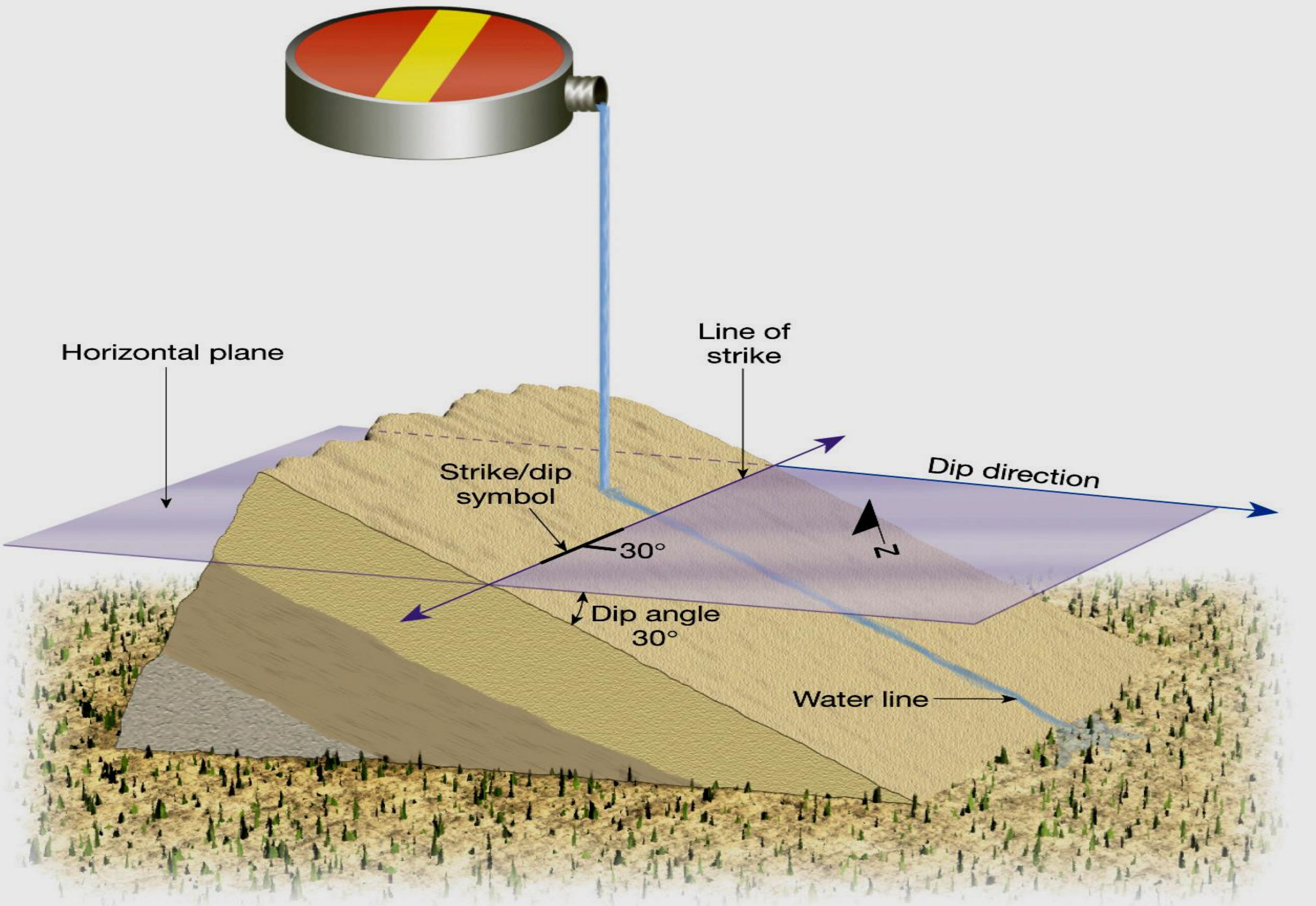
The dip direction is used to distinguish between two planes which have the same strike and the same angle of dip

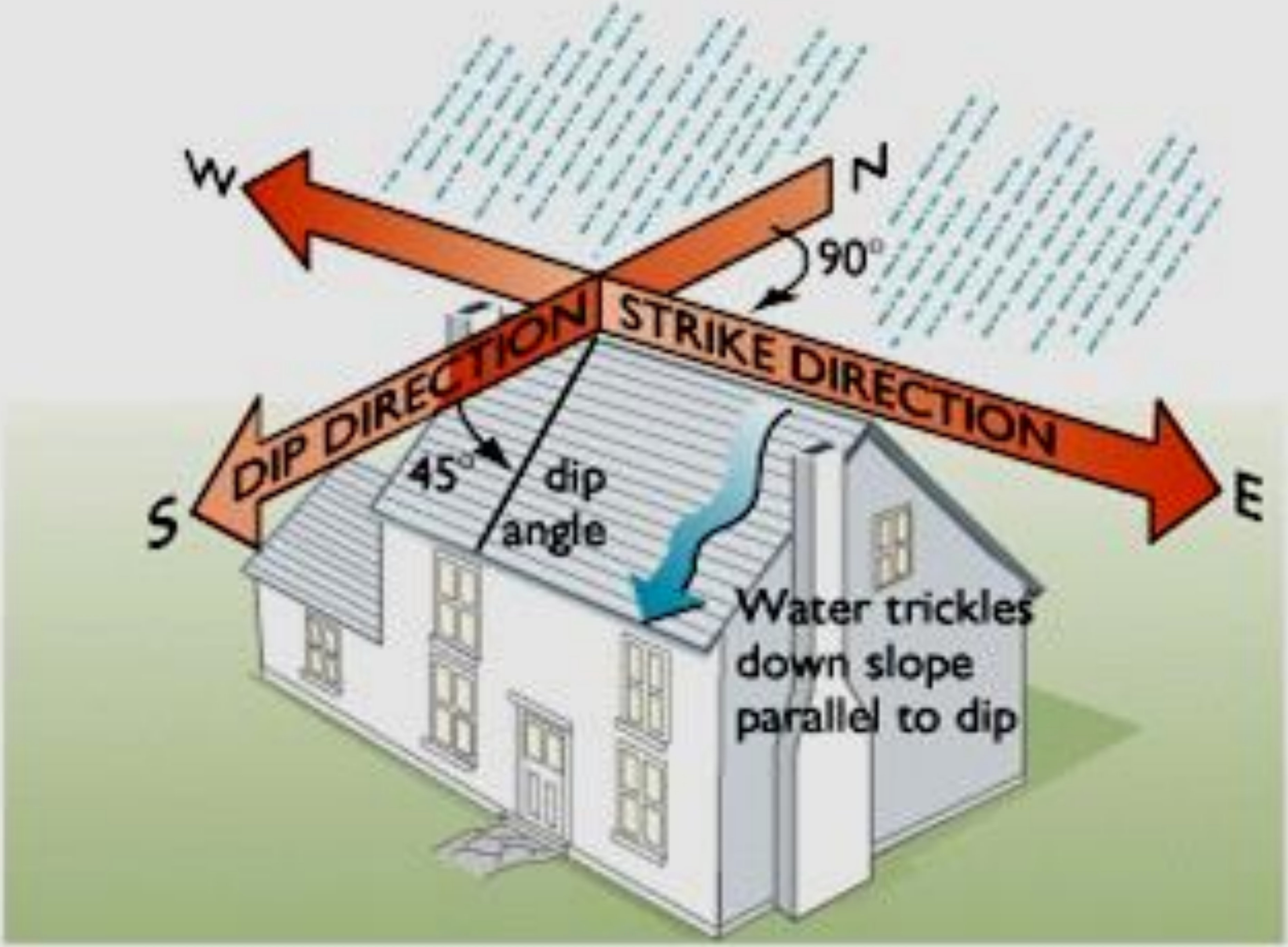


Attitude of Planar Structures

- The attitude of planar structures is defined by the strike, dip
  - **Strike** is the bearing of a horizontal line on the plane (a scalar), e.g., N40°E
  - **Dip** is the inclination of the plane, measured down
    - dip is a vector; it gives the direction and amount of dip of the plane. Example for dip: 80°N
      - 80° is the amount, N is the direction
- **Example of planar structure:** bedding, fault, fold axial plane, layering in lava, foliation

Strike and dip of a rock layer




W
N
90°
DIP DIRECTION
STRIKE DIRECTION
S
E
45°
dip
angle
Water trickles
down slope
parallel to dip

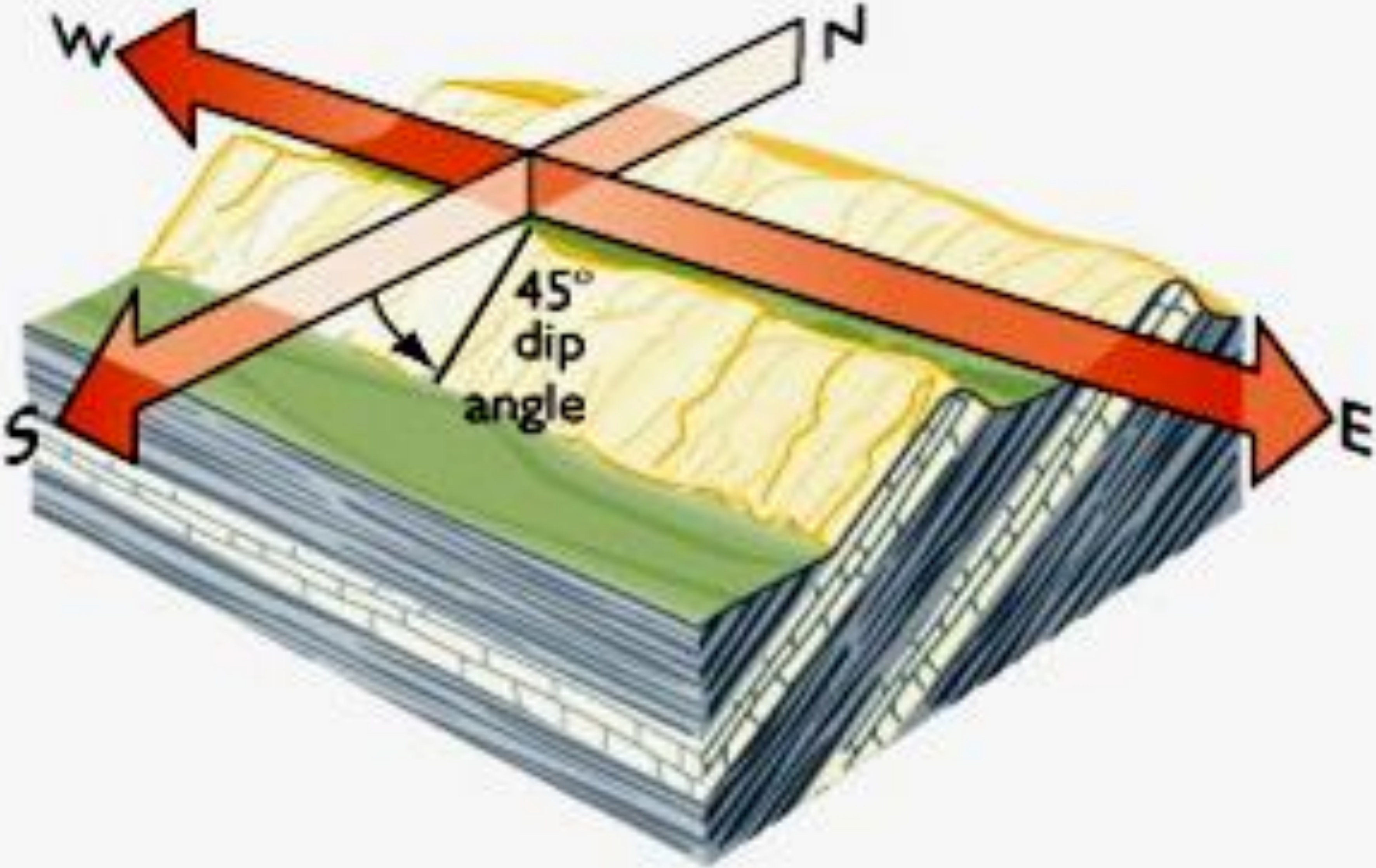


Fig. 10.4

Strike and Dip of a Dyke- Southern Sinai

Strike and Dip of a Dyke- Southern Sinai

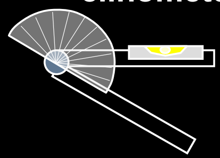
Dipping Sedimentary Beds

Cockscomb Ridge, S. Utah

Cockscomb Ridge, S. Utah

So, altogether there are three measurements to be made to represent the orientation of a planar structure

clinometer



Strike
Dip
Dip direction

compass

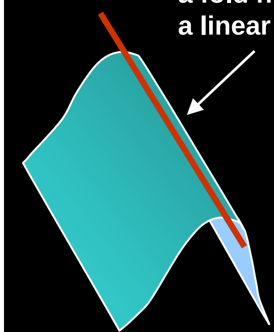
These are recorded in the following format:

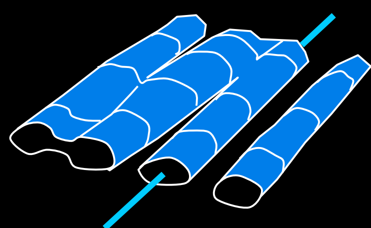
Strike ; Dip Dip direction

e.g. N20W ; 35   SW

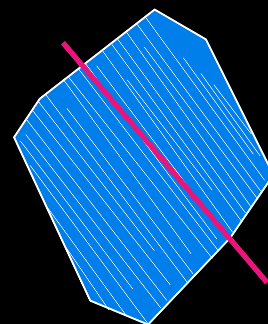
Linear structures are very common too

a fold hinge is
a linear structure



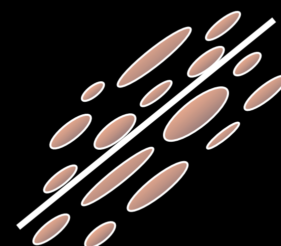


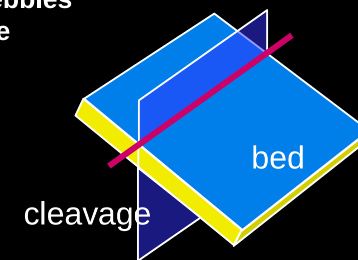
boudins are linear structures



striations are linear structures on a plane

parallel long axes of pebbles define a linear structure

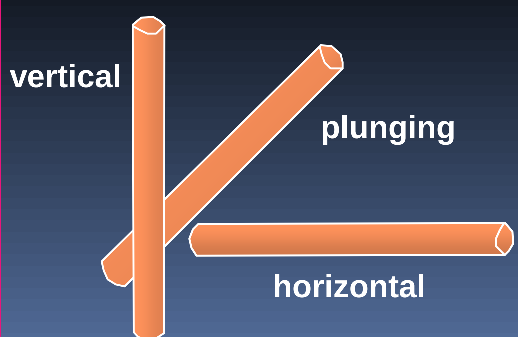




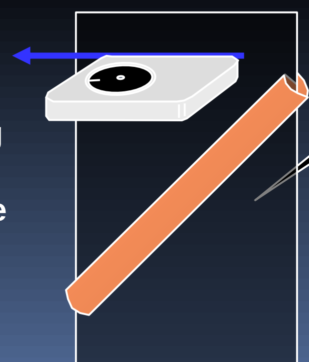
the intersection of bedding and cleavage is a linear structure on a plane

Orientation of Lines

The measurement of the orientation of lines is easier than for planes, and requires only two measurements



TREND
of the
plunging
linear
structure



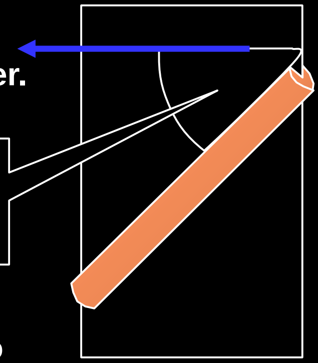
First, construct the vertical plane
the plunging linear structure. containing

The strike of this plane is measured with a compass.

Specifically the direction towards which the line is
plunging should be measured.

This called the <u>TREND</u> of the line

Then the angle in this vertical plane from the trend line down to the plunging line is measured using a clinometer.



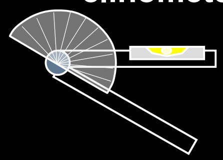
This called the <u>PLUNGE</u> of the linear structure

PLUNGE varies from 0º to 90º

Notice that a vertical line does not have a trend

So, altogether there are two measurements to be made to represent the orientation of a linear structure:

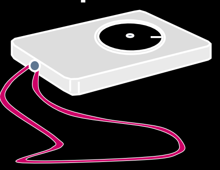
clinometer



Trend

Plunge

compass



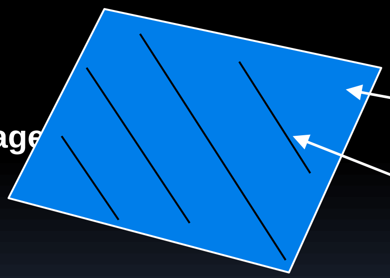
These are recorded in the following format:

Plunge → Trend

e.g. 25 → S40W

There is another way to measure the orientation of a line.

It is particularly useful when the linear structure naturally occurs as a feature on a plane e.g. striations on a fault, crenulations on a cleavage



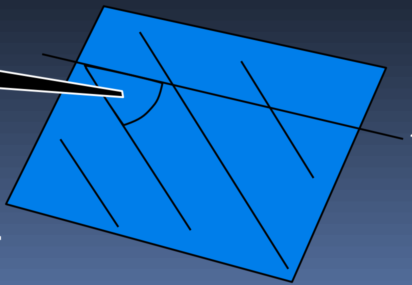
fault plane

striations

The angle from the strike of the plane down to the lineation is measured.

This is called the <u>PITCH</u> of the line

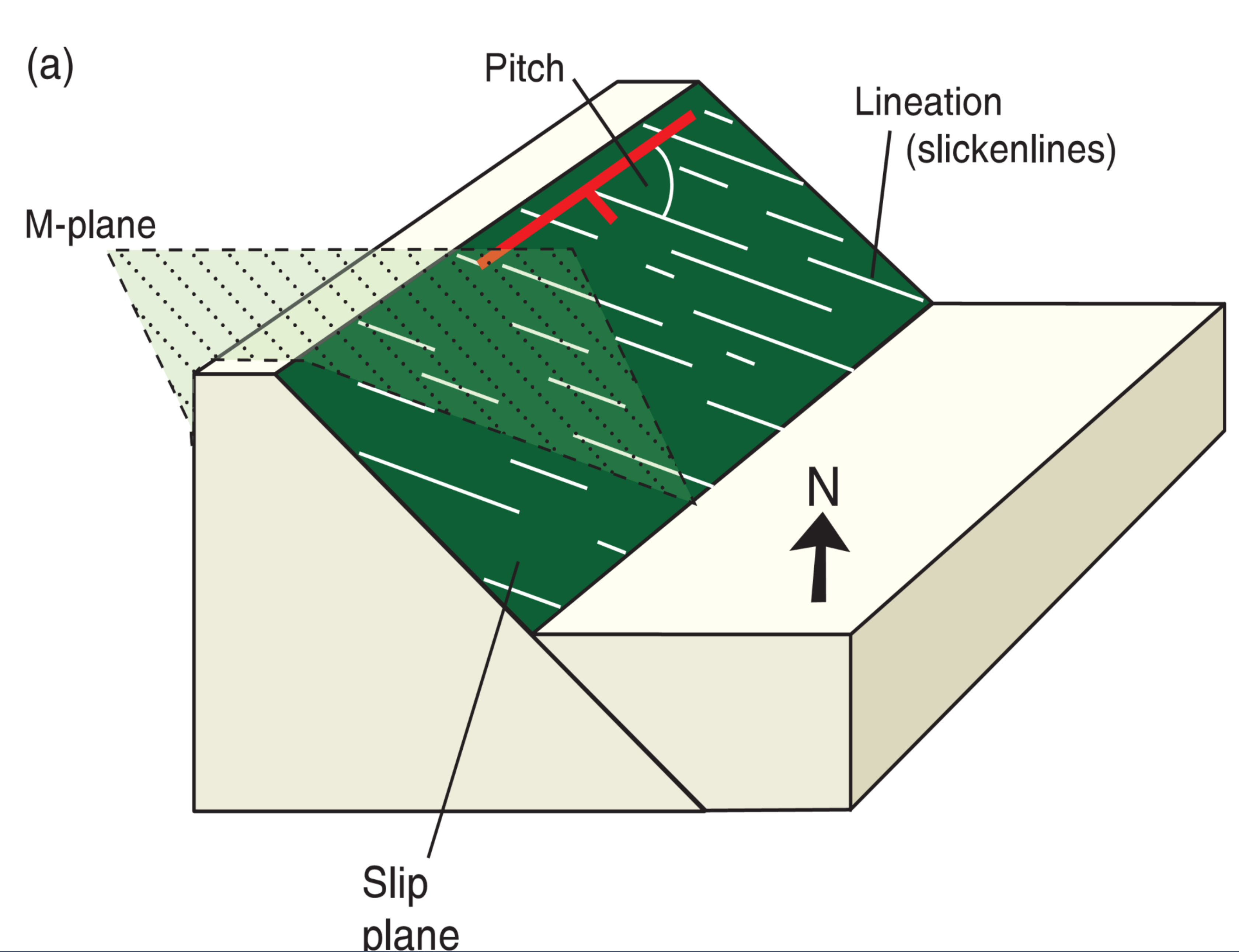
PITCH varies from 0º to 90º



As with dip direction, we must also record pitch direction simply as a quadrant e.g. NE, SW etc

The pitch is measured with a clinometer

This is because there are two possible lines with the same pitch angle but opposite pitch directions



Schematic illustration of pitch as measured on a fault surface.

Attitude of Linear Structures

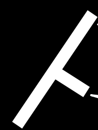
- The attitude of linear structures is defined by the **trend, plunge** (***together they define a vector***)
  - **Trend** is the bearing of the line
  - **Plunge** is the inclination of the line
- Linear structure are also defined by their pitch on a given plane:
  - **Pitch**: The acute angle between the line and the strike of the plane on which the line lies

How do we represent the measurements of planes and lines on a map?

The first most important thing to do with structural orientation data is to put it on a map

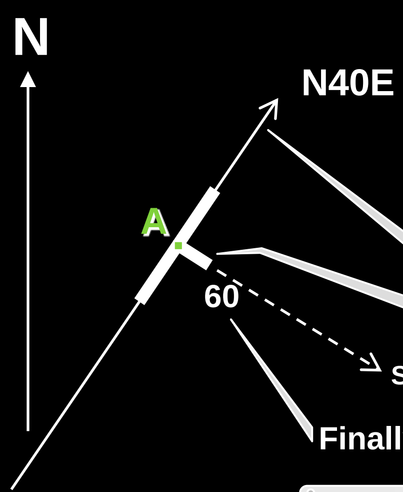
Both must be correctly oriented on a map

For **planar measurements** we use a symbol called the **dip-and-strike symbol**



The longer line of the symbol represents the strike

The short stroke represents the dip direction



For example, we will plot the dip-and-strike symbol for a bedding measurement of **N40E; 60 SE** at location **A**

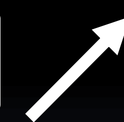
First, we draw a line through A in the direction N40E and plot in strike part of the symbol

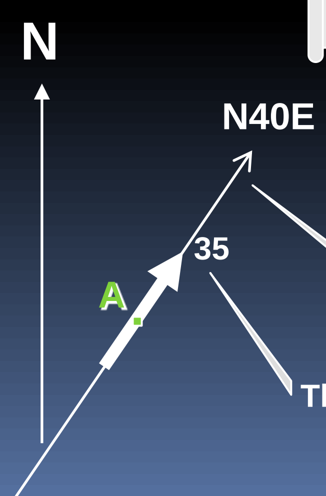
Then the dip stroke of the symbol is drawn. This must be in the direction of the dip

SE quadrant dip direction

Finally, the dip angle is written next to the dip stroke. In this example it is 60 degrees

For **linear measurements** it is even easier. We use an **arrow symbol**





For example, we will plot the arrow symbol for a fold hinge measurement of **35 → N40E** at location **A**

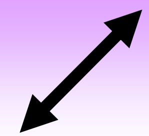
First, we draw a line through A in the trend direction of the hinge i.e. N40E and draw the arrow

Then the plunge angle (here 35 degrees) is written at the tip of the arrow symbol

The two symbols have to be modified to represent vertical and horizontal planes and lines

The vertical bed is represented by dip strokes in both directions (because it can be considered to dip 90 in either direction)

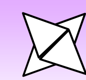
no dip or plunge values need to be added here



The horizontal hinge is represented by a double headed arrow (because it can be considered to plunge zero in either direction)

The horizontal bed has no unique strike but can be considered to dip zero towards all quadrants, and we use the dip strokes to show it

the circle here helps to distinguish two rather similar looking symbols

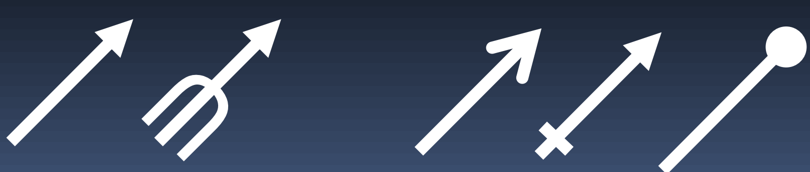


The vertical hinge has no unique trend but can be considered to plunge 90 degrees towards all quadrants, and we use the arrow heads to show it

There also needs to be different looking dip-and-strike symbols to distinguish beds, cleavages, joints etc on a map

beds foliations joints veins

Another set of different arrow symbols is needed for other linear structures



fold hinges striations, boudins, mineral lineations etc.

These symbols must be listed and explained on any map legend


Any
Questions?

Fundamental Structures

- Primary Structures: These are sedimentary structures that may be in strata *prior* to deformation. They may be quite useful as strain markers (giving us an initial state) and as way-up indicators, etc.

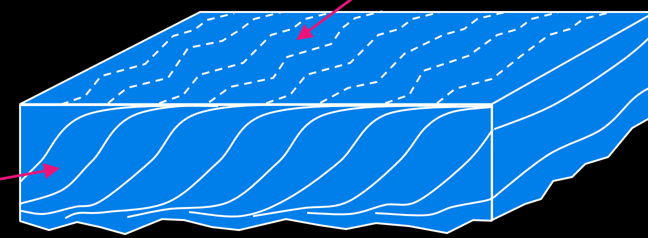
- They must *not* be mistaken for **secondary structures**, which are the *result* of deformation.

Primary Structures

We know that primary structures form at the same time as the host rocks are forming.

Primary structures are either <u>sedimentary</u> or <u>igneous</u> only.
Structures which form during metamorphism are secondary.

Layering (bedding and lava flows) is the most common and important primary structure, and most other primary structures can be related to their position in the layers:



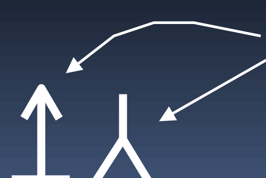
What do primary structures tell us?

They tell us:

* the environmental conditions at the time of sedimentation etc.
* geometry of the basin of deposition
* the original orientation of the rocks (horizontal)
* the stratigraphic sequence ("younging")

top of the bed

bottom of the bed

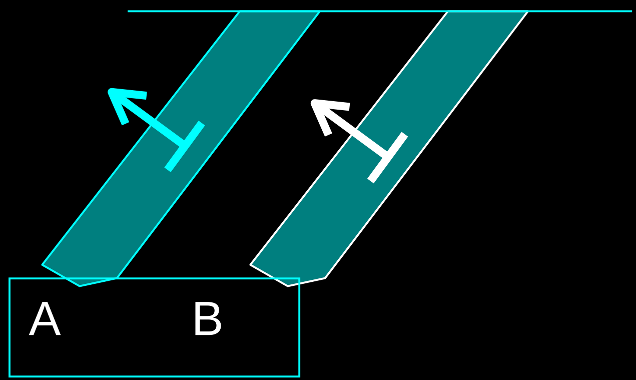


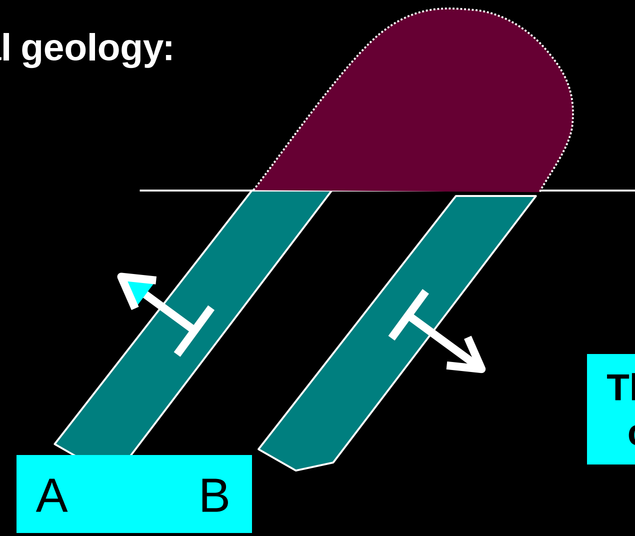
The younging vector points from the base of the bed towards the top of the bed

This is a very important feature to look for when mapping

An example of the use of “younging” in structural geology:

A and B are beds with the same lithology





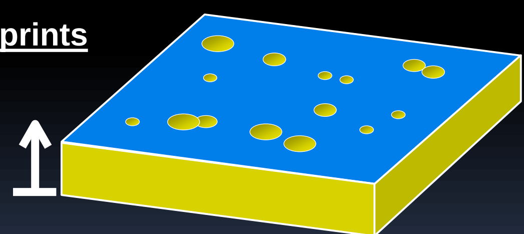
This is quite common

If A and B are younging in the same direction then A is a younger bed than B and we probably have a normal stratigraphic sequence.

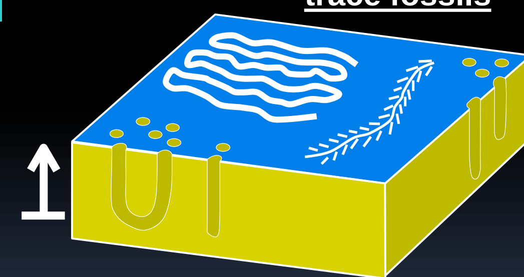
If A and B are younging in opposite directions, it is likely that A and B are the <u>same bed</u> repeated by tight folding and the sequence is not a normal stratigraphic one.

Primary structures formed at the tops of beds

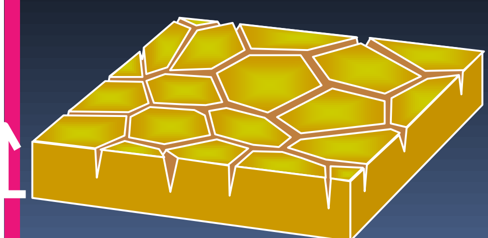
rain prints



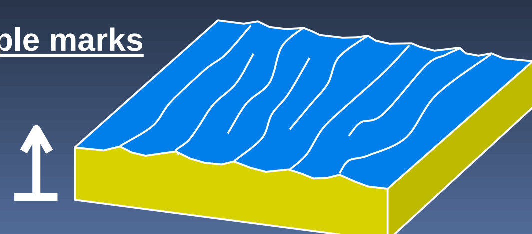
trace fossils



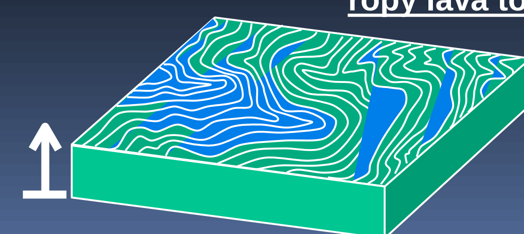
mud cracks



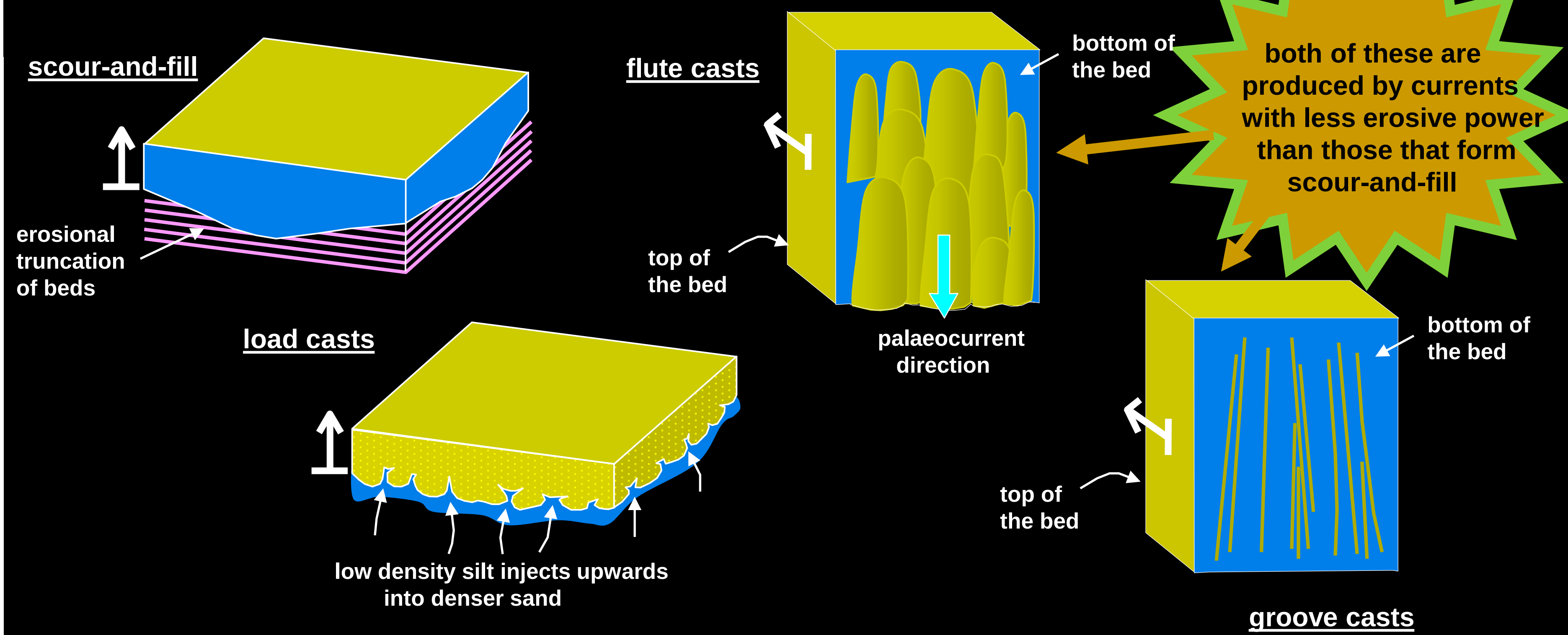
ripple marks



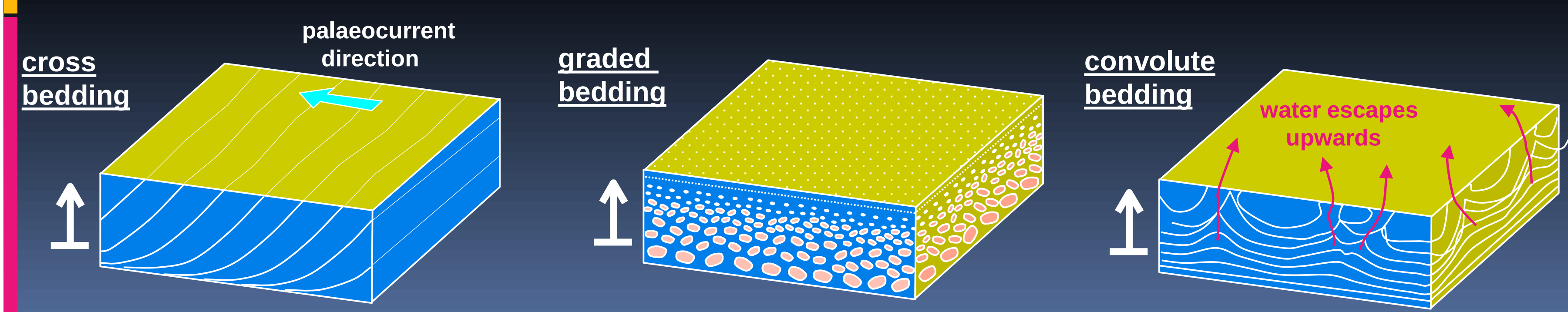
ropy lava top



Primary structures formed at the bottoms of beds



Primary structures formed within the beds (internal structures)

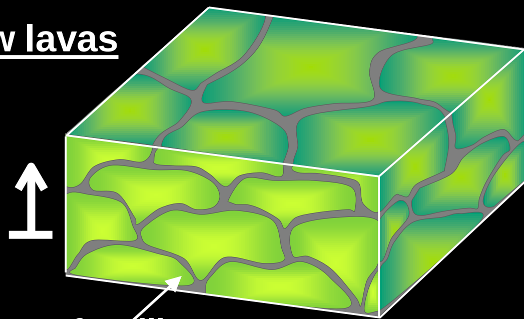


Convolute Bedding

Bahariya Oasis
Gebel El Dist

Some more primary volcanic structures which are useful for younging

pillow lavas



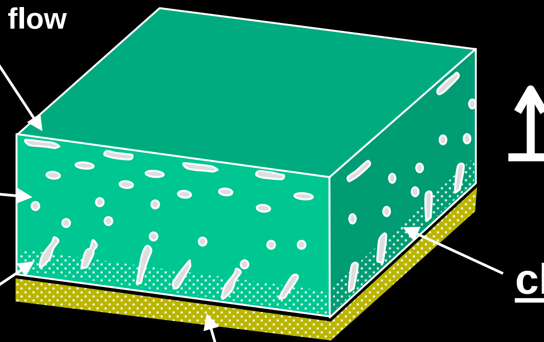
the base of a pillow conforms to the shape of the pillows below

vesicle shapes

disc-shaped vesicles near top of the flow

spherical vesicles

tubular vesicles at base of the flow

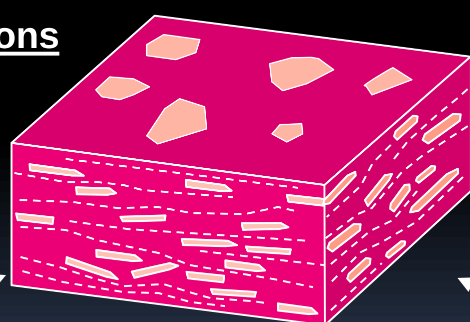


chilled lava base

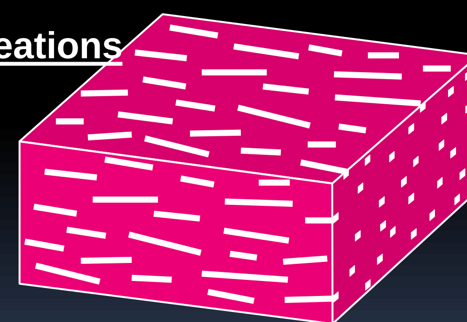
baked contact

Some other primary igneous structures

flow foliations



flow lineations

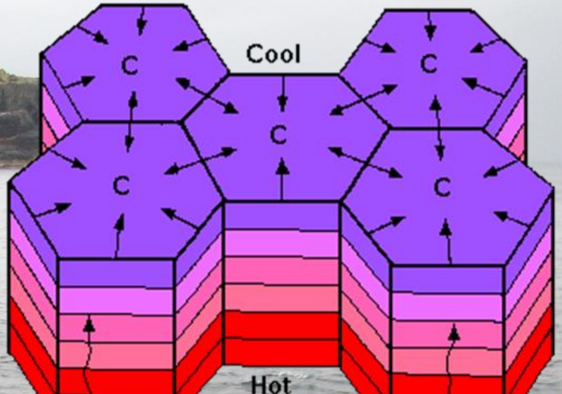


schlieren are complex flow bands defined by concentrations of dark minerals, e.g. biotite

These form planar and linear fabrics

These primary igneous fabrics may be found in both volcanic and intrusive igneous rocks

Columnar Joints



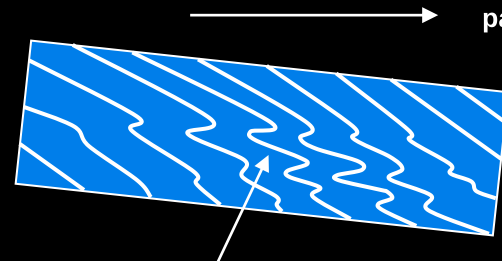
Columnar Joints

Columnar Joints

- Extension fractures characteristic of tabular extrusive igneous rocks
  - i.e., form in lava flow, sill dike

There is an internal structure called a SLUMP which forms by collapse of wet sediments in response to tilting or agitation or loading:

slumping is particularly common in cross-bedded strata because the cross-beds are already tilted



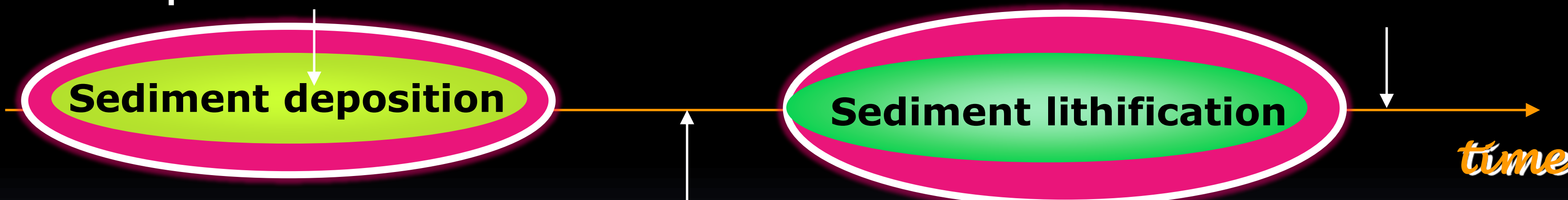
They are formed by sliding downslope so they are good palaeoslope indicators

Slumps are folds, often tight but confined to a single bed

Since they form after deposition they cannot be truly primary structures

Structures formed *during* deposition are PRIMARY

Structures formed *after* lithification are SECONDARY



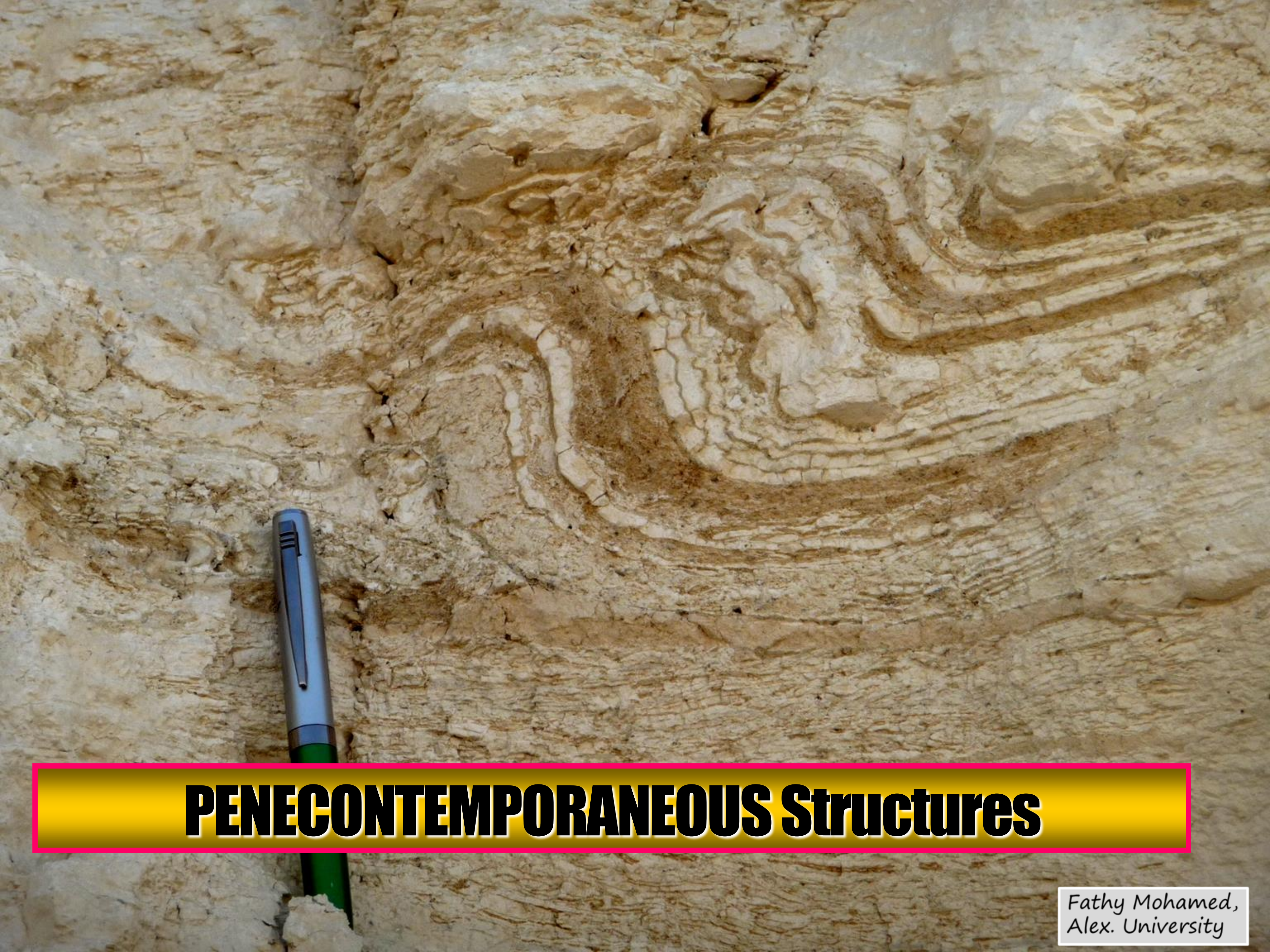
e.g. sand

e.g. sandstone

Structures formed after deposition but before any lithification processes are called PENECONTEMPORANEOUS

e.g. slumps, mudcracks

PENECONTEMPORANEOUS Structures



PENECONTEMPORANEOUS Structures
Fathy Mohamed,
Alex. University

Unconformaties

- **Boundaries separating one rock unit from another**
- **Two types:**
- **1. Normal conformable**
- **2. Unconformable**

Conformable Bed Contacts

- Horizontal contact between rock units with no break in deposition or erosional gaps
- no significant gaps in geologic time

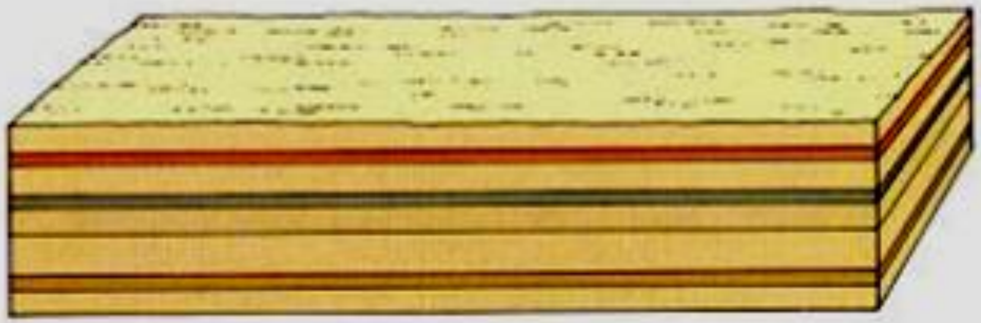
Unconformable Contacts

- Erosion surfaces representing a significant break in deposition (and geologic time)
- angular unconformity
- disconformity
- non-conformity

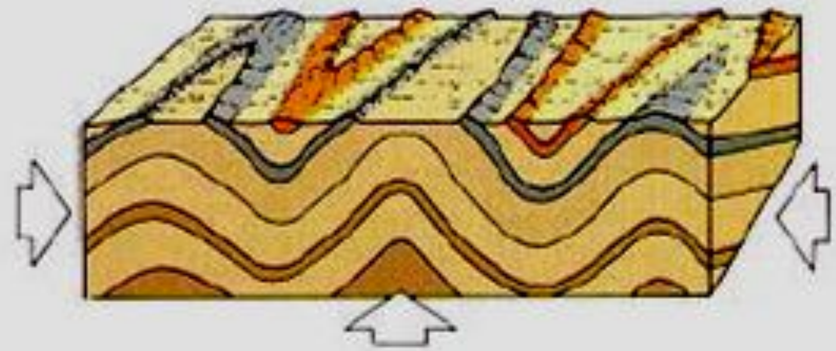
Angular Unconformity

- Bedding contact which discordantly cuts across older strata
- discordance: strata are at an angle to each other

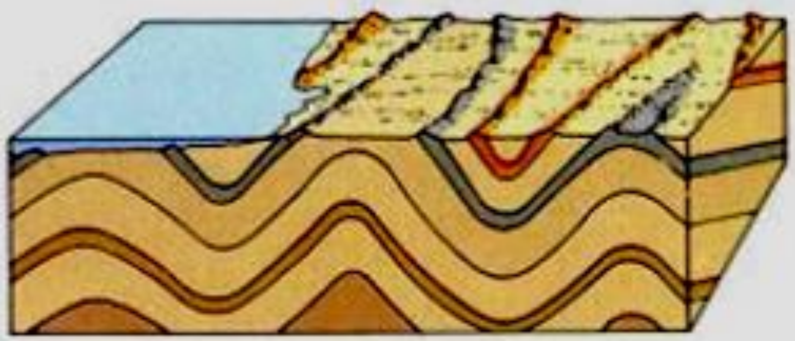
Angular Unconformity



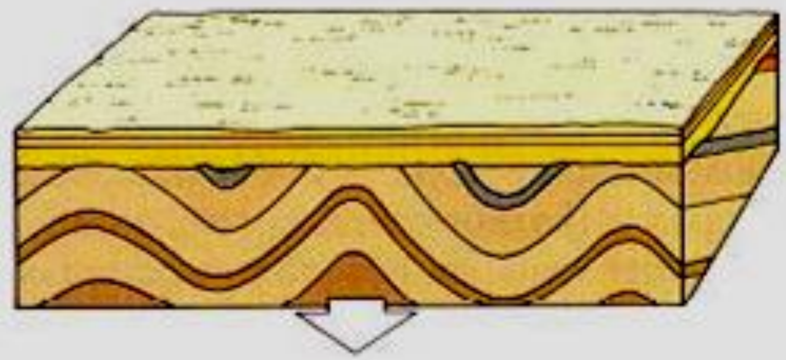
1. Sediments deposited



2. Sequence folded and surface eroded

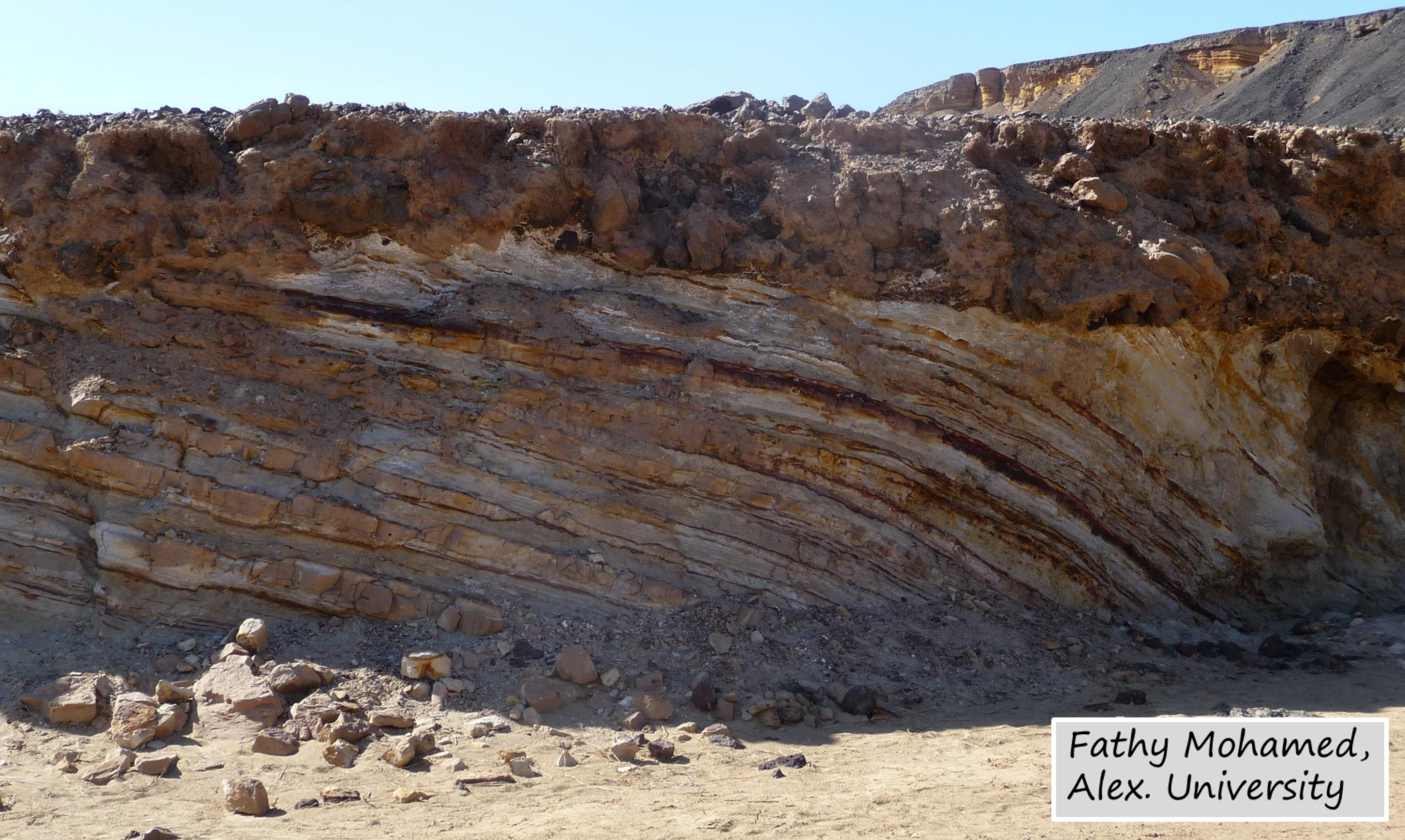


3. Marine transgression



4. Deposition of second sequence, subsidence

Angular Unconformity, with conglomerate erosional surface Bahariya Oasis



Angular Unconformity, with conglomerate erosional surface Bahariya Oasis

Disconformity

Erosional gap between rock units without angular discordance
example:
fluvial channel cutting into underlying sequence of horizontally bedded deposits

Nonconformity

- Sedimentary strata overlying igneous or metamorphic rocks across a sharp contact
- example: Precambrian-Paleozoic contact in Jordon

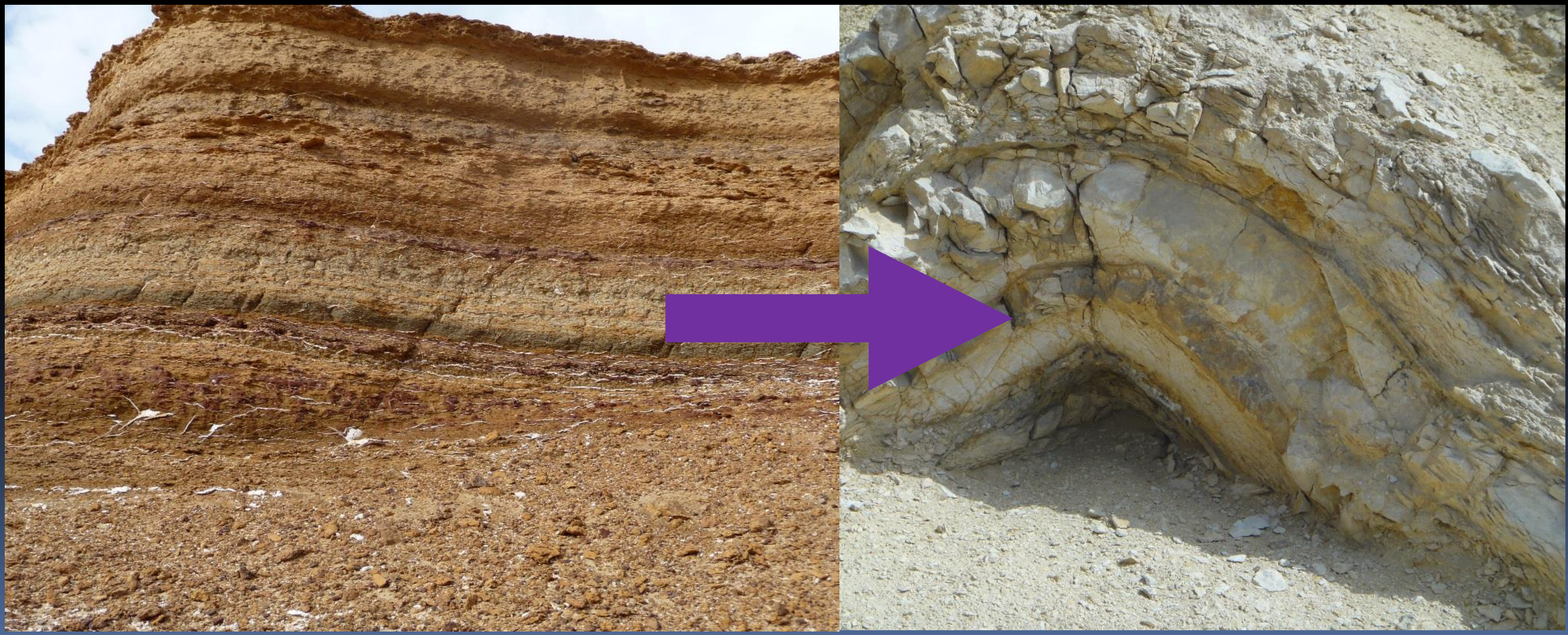

Nonconformity
Fathy Mohamed,
Alex. University

Relations Structural

- The structural relations between bed contacts are important in determining:
- presence of tectonic deformation/uplift
- sequence of events
- relative ages of rock units
- principle of original horizontality
- principle of original lateral continuity
- principle of cross-cutting
- principle of inclusion

Principle of Original Horizontality

- Sedimentary rocks are deposited as essentially horizontal layers (Steno, 1600's)
- exception is cross-bedding (e.g. delta foresets)
- dipping sedimentary strata implies tectonic tilting and/or folding of strata



Principle of Original Lateral Continuity

Sedimentary strata extend as laterally continuous layers in all directions within a basin until:

- they thin and pinch out
- terminate against the basin edges

Cross-cutting Relations

Cross-cutting Relations

Often several cross-cutting relationships are present

- how many events in this outcrop?

Principle of Inclusion

- Inclusions within a host rock are always older than the host (J. Hutton)

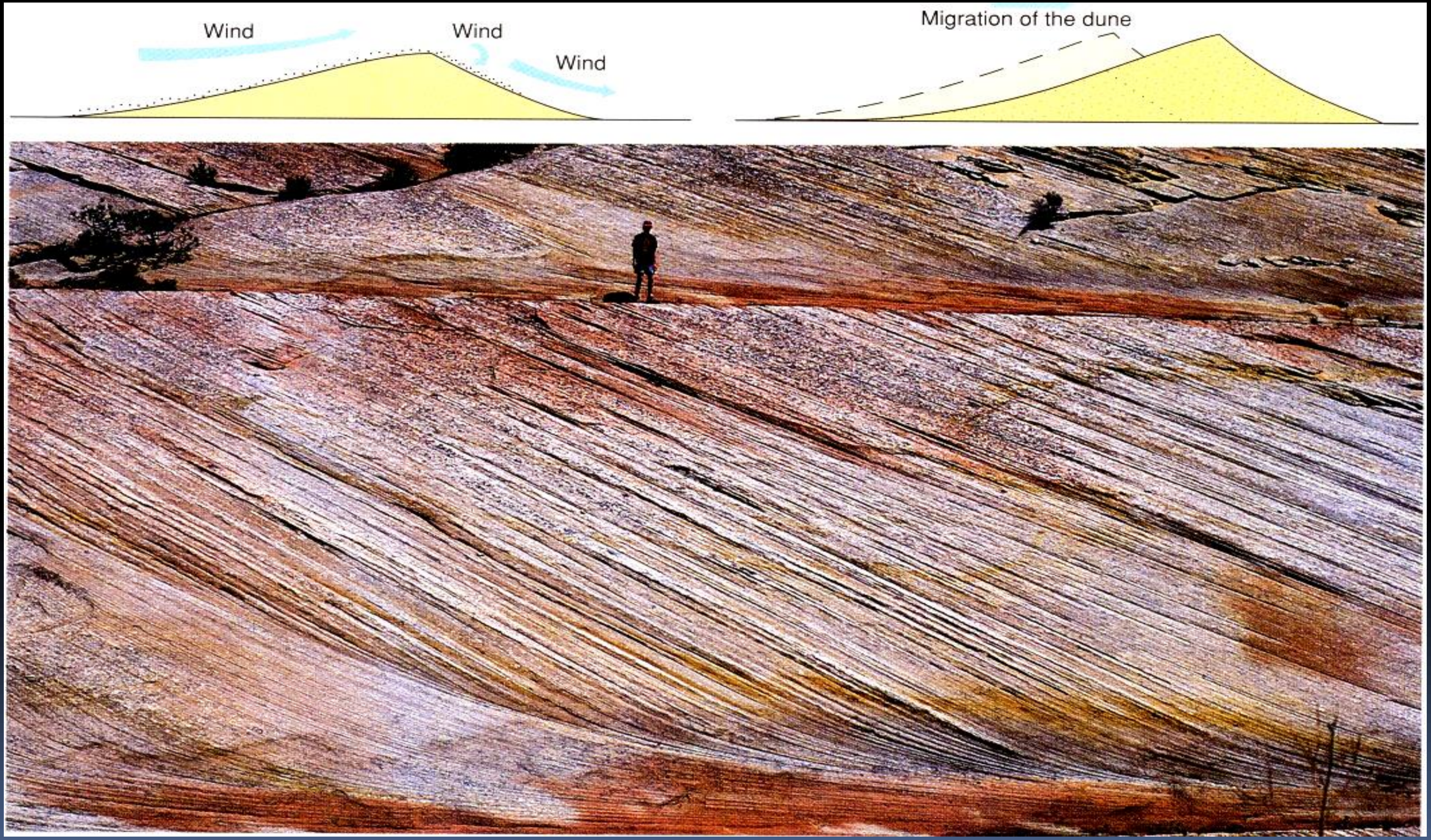
Primary Sedimentary Structures

Structures acquired during deposition of sedimentary rock unit

- horizontal bedding (stratification) is most common structure in sedimentary rocks

Primary Sedimentary Structures

- Cross-bedding - inclined stratification recording migration of sand ripples or dunes



Large-scale aeolian cross-beds, Utah

Cross Bedding in Braided sandstone, Bahariya Oasis of Egypt

Cross Bedding in Nubia Sandstone- Qift-Quseir Road, Eastern Desert

Primary Sedimentary Structures

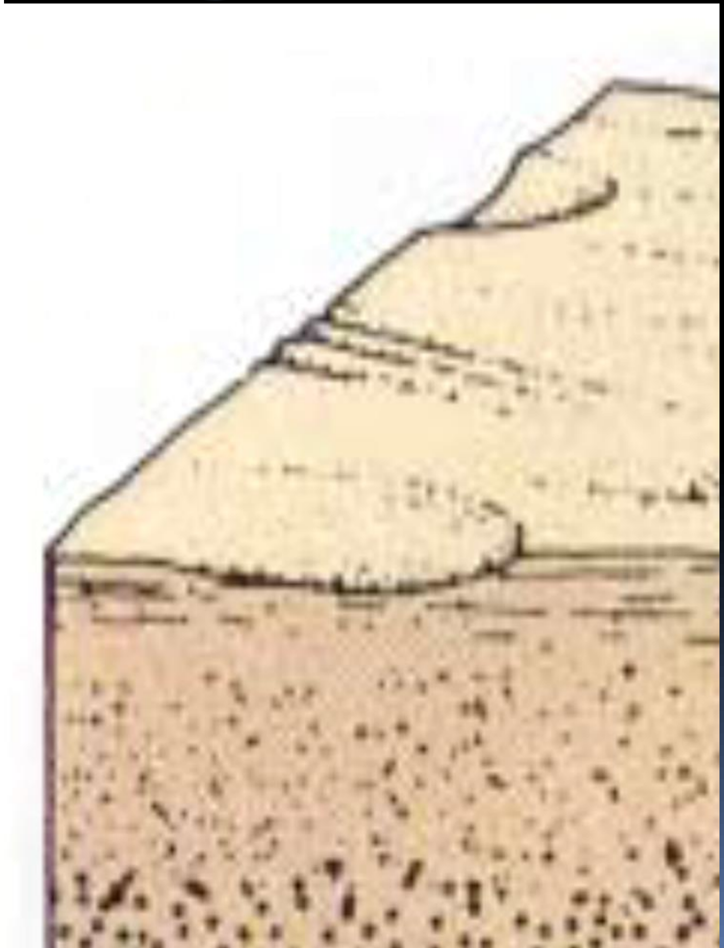
Ripples - undulating bedforms produced by unidirectional or oscillating (wave) currents

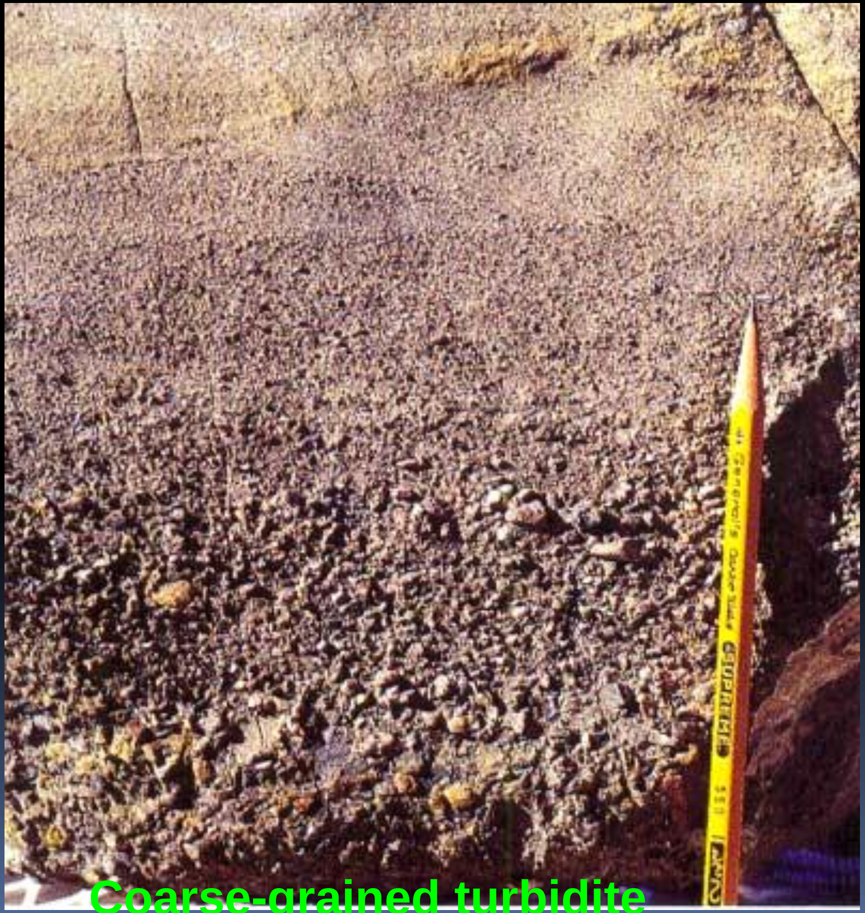

Ripple
marks

Primary Sedimentary Structures

Graded bedding - progressive decrease in grain-size upward in bed

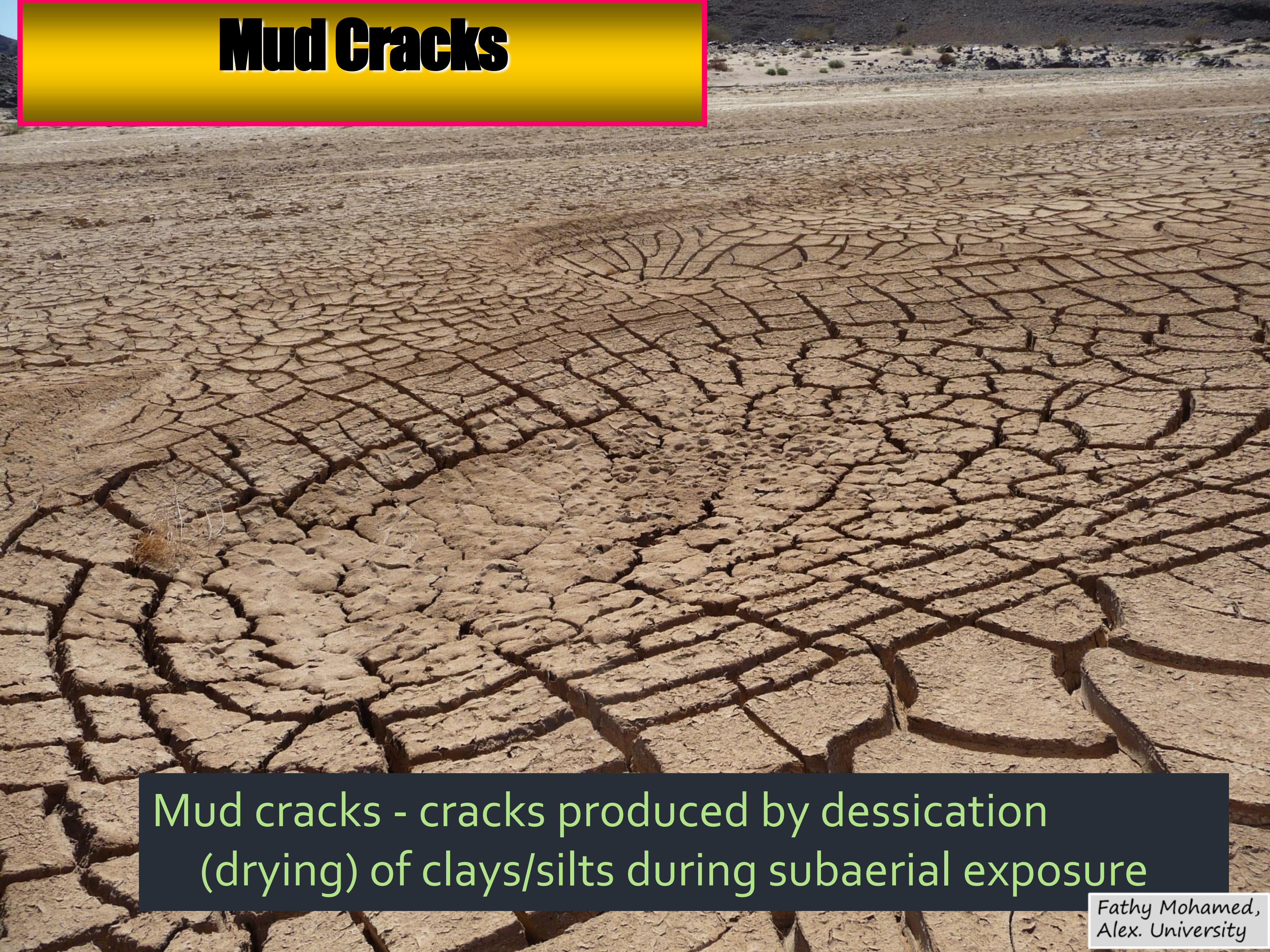
- indicator of upwards direction in deposit
- e.g. turbidites





Coarse-grained turbidite

Mud Cracks

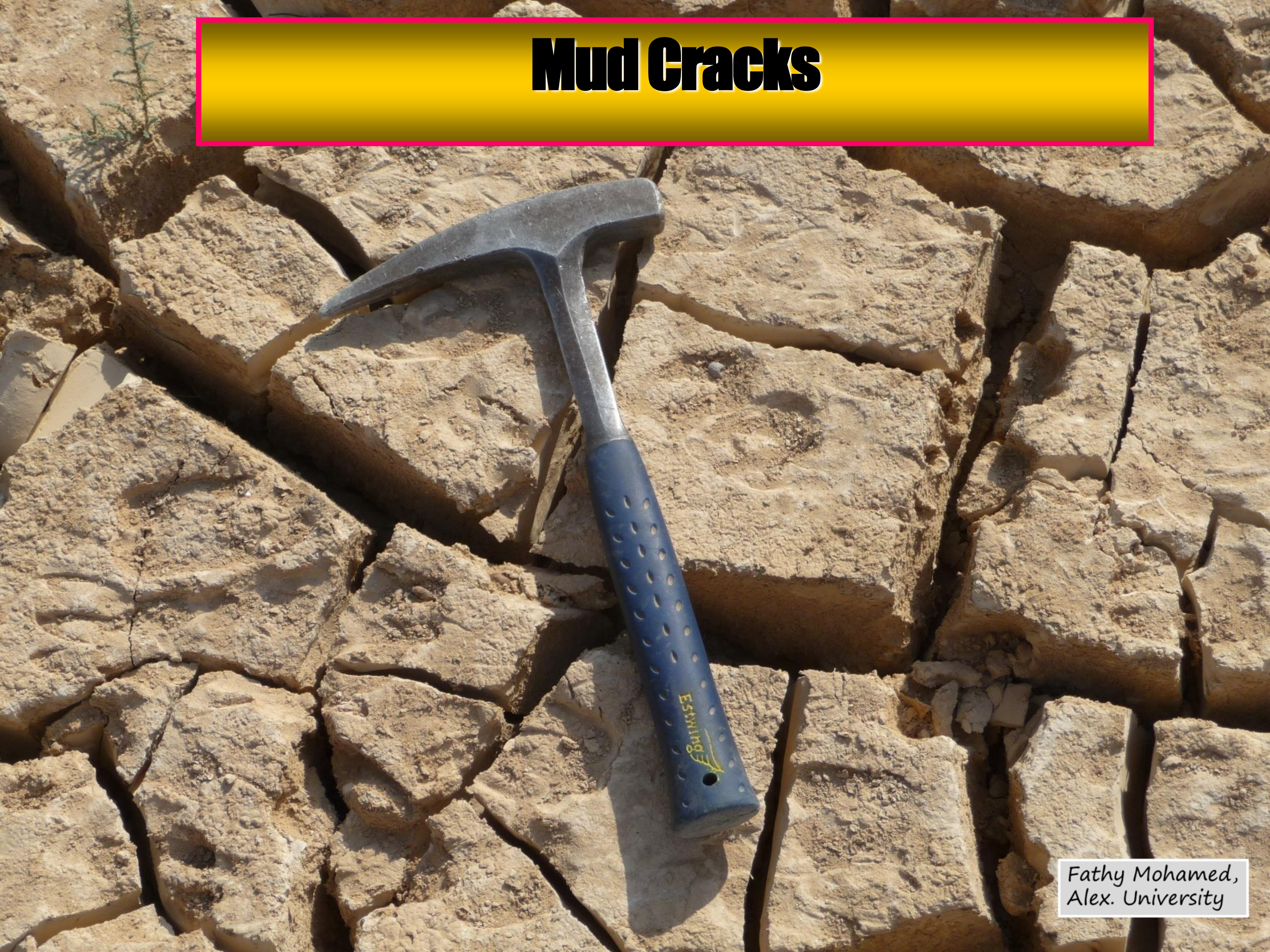


Mud cracks - cracks produced by dessication (drying) of clays/silts during subaerial exposure

Fathy Mohamed, Alex. University


Mud Cracks
Fathy Mohamed,
Alex. University

Mud Cracks



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Alex. University

Primary Sedimentary Structures

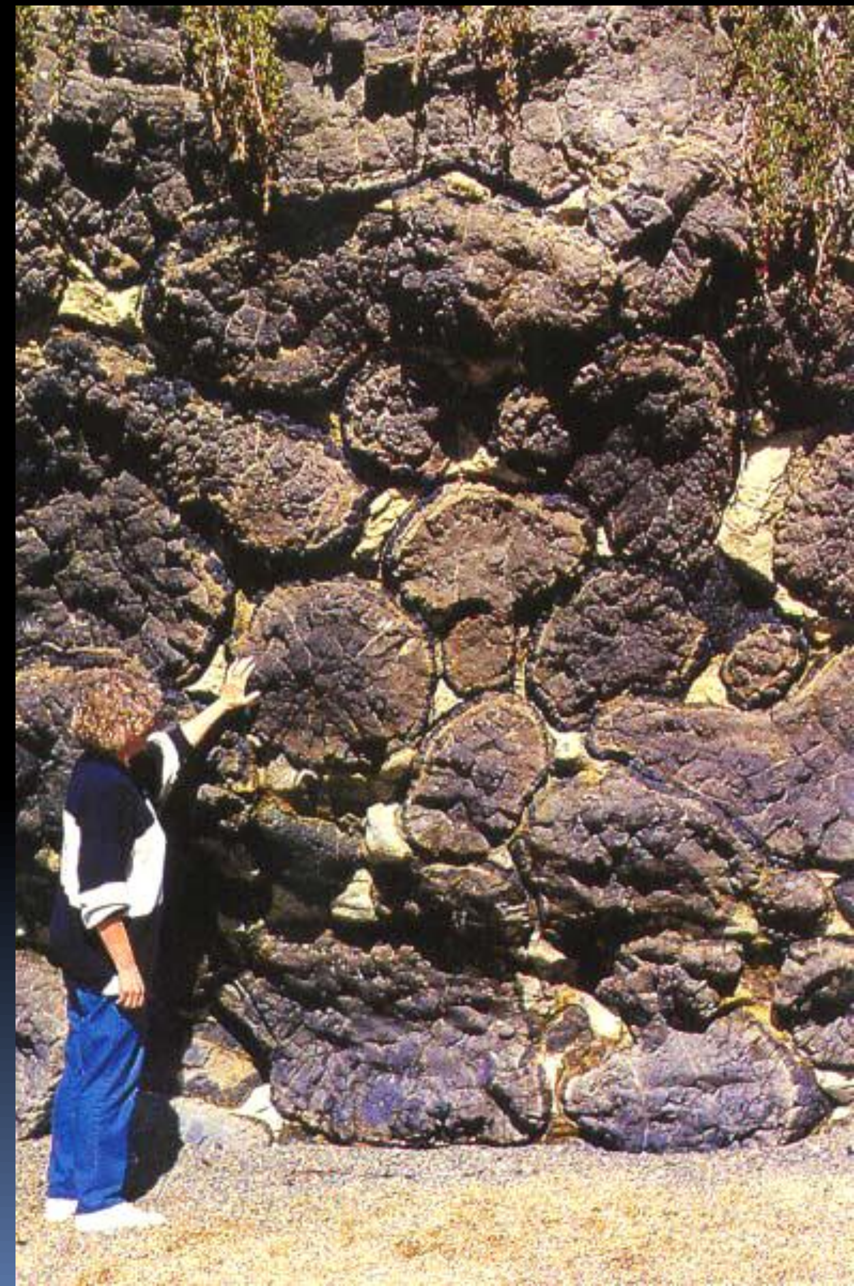
- Sole marks - erosional grooves and marks formed by scouring of bed by unidirectional flows
- good indicators of current flow direction

Sole marks on base of sandstone bed

Primary Igneous Structures

Pillow lavas - record extrusion and quenching of lava on sea floor

- convex upper surface indicates way up



Primary Igneous Structures

Flow stratification - layering in volcanic rocks produced by emplacement of successive lava sheets

- stratification of ash (tephra) layers

Stratified pyroclastic flow

Sequence of basaltic flows

Quizzes

Deformation

Deformation

- **Deformation** is a general term that refers to all changes in the original form and/or size of a rock body
- Most crustal deformation occurs along plate margins
- Deformation involves
  - **Force** – that which tends to put stationary objects in motion or changes the motions of moving objects

Deformation

- **Deformation involves**
  - Stress - force applied to a given area
  - Types of stress
    - Compressional stress – shortens a rock body
    - Tensional stress – tends to elongate or pull apart a rock unit
    - Shear stress – produces a motion similar to slippage that occurs between individual playing cards when the top of the stack is moved relative to the bottom

Stress

Uniform –

compressional

Differential –

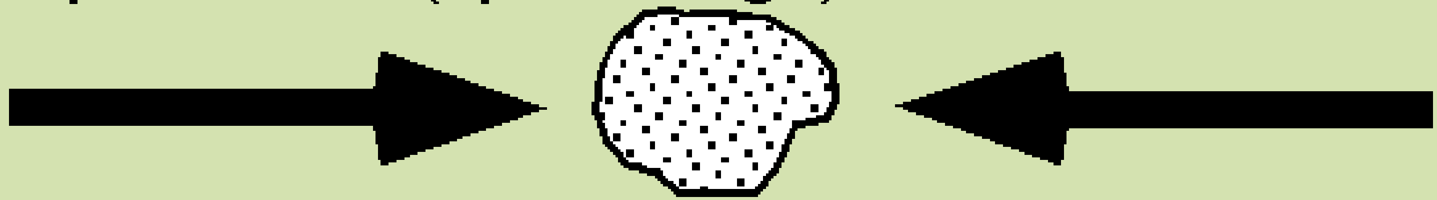
compressional

tensional

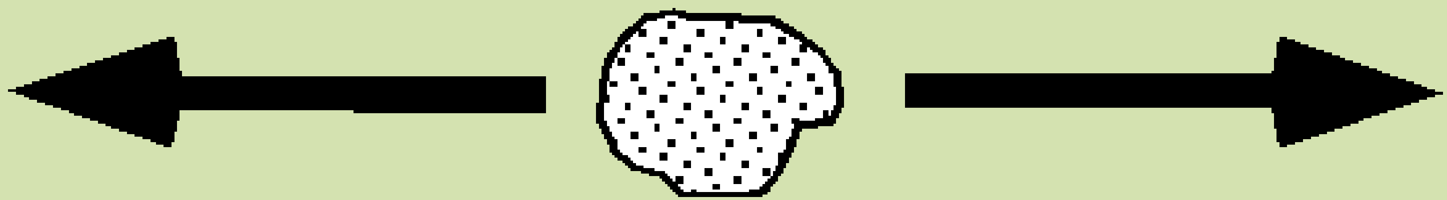
shear

STRESS = F/A (usually kgf/cm^2 or lbs./in^2)

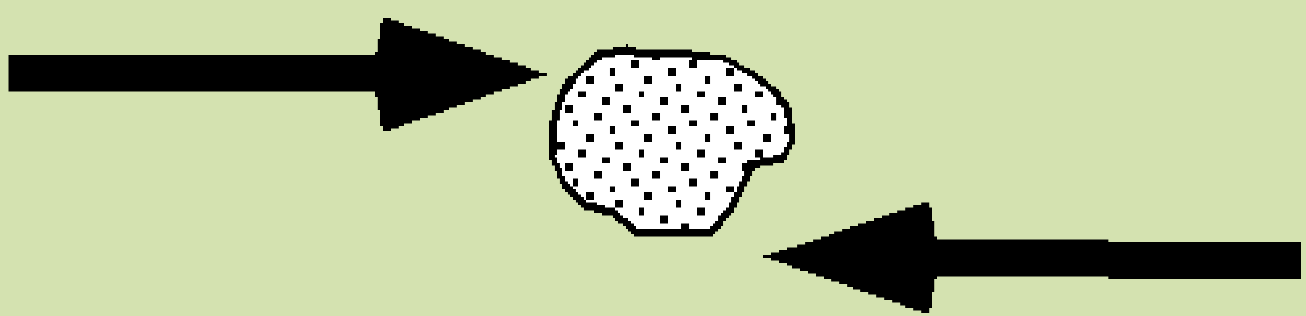
Compressive ("pushing")



Tensile ("pulling")

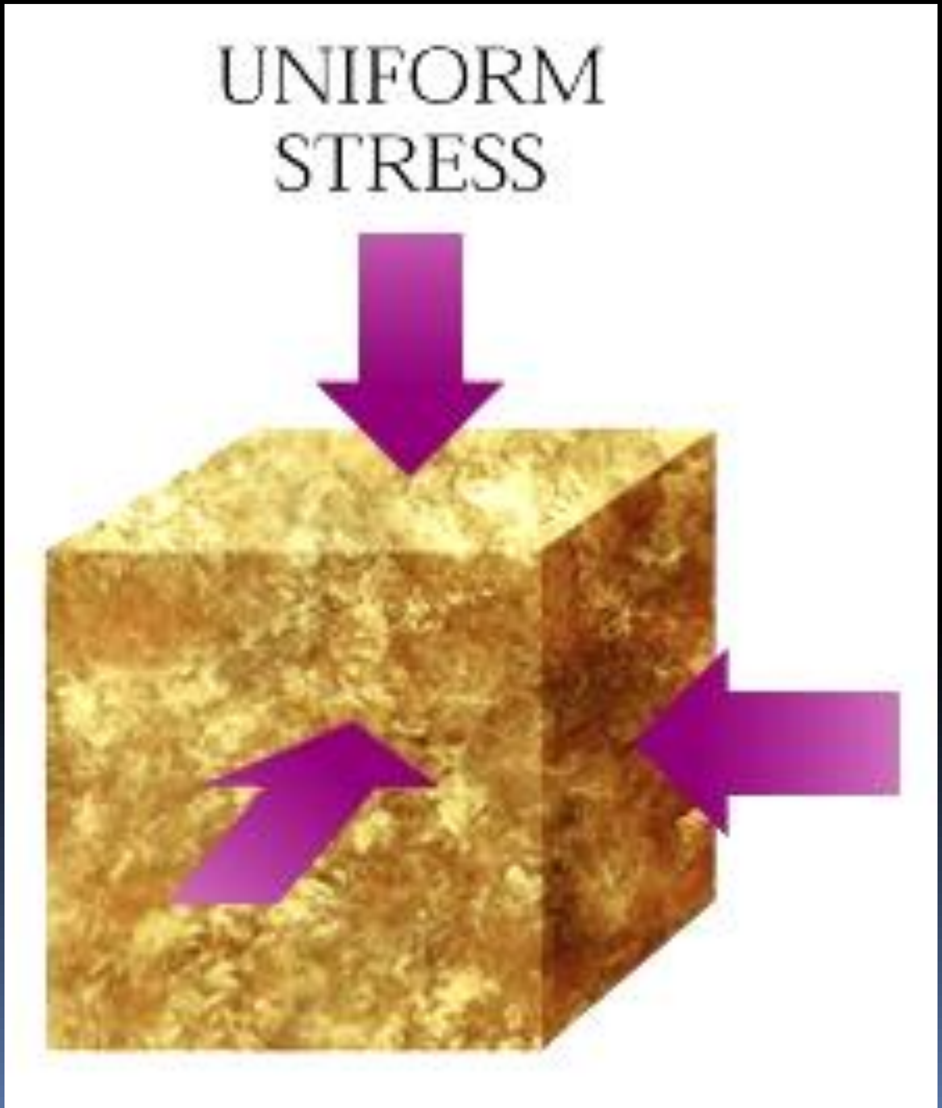


Shear (rotational)



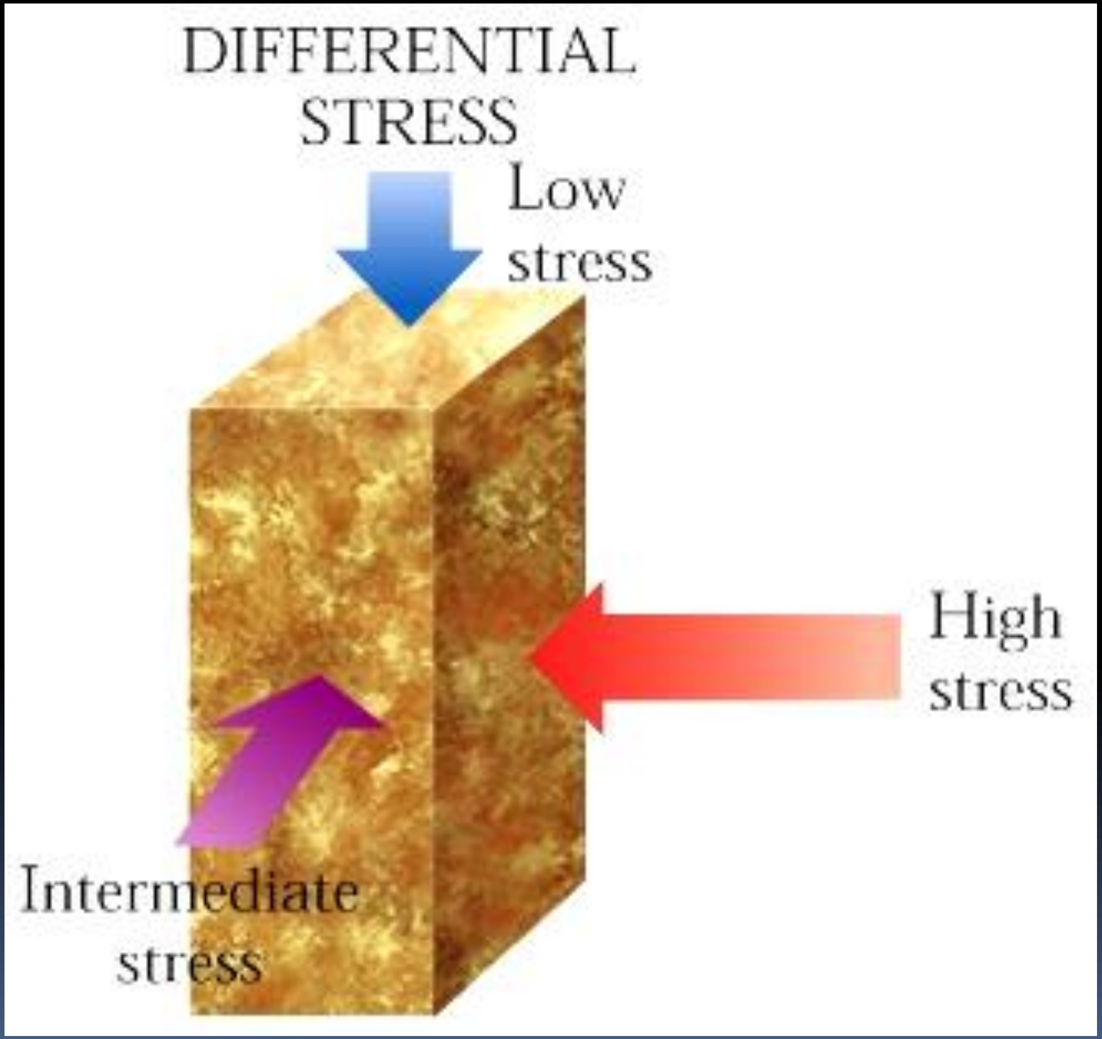
Types of Stress

- Uniform stress – equal force applied in each direction

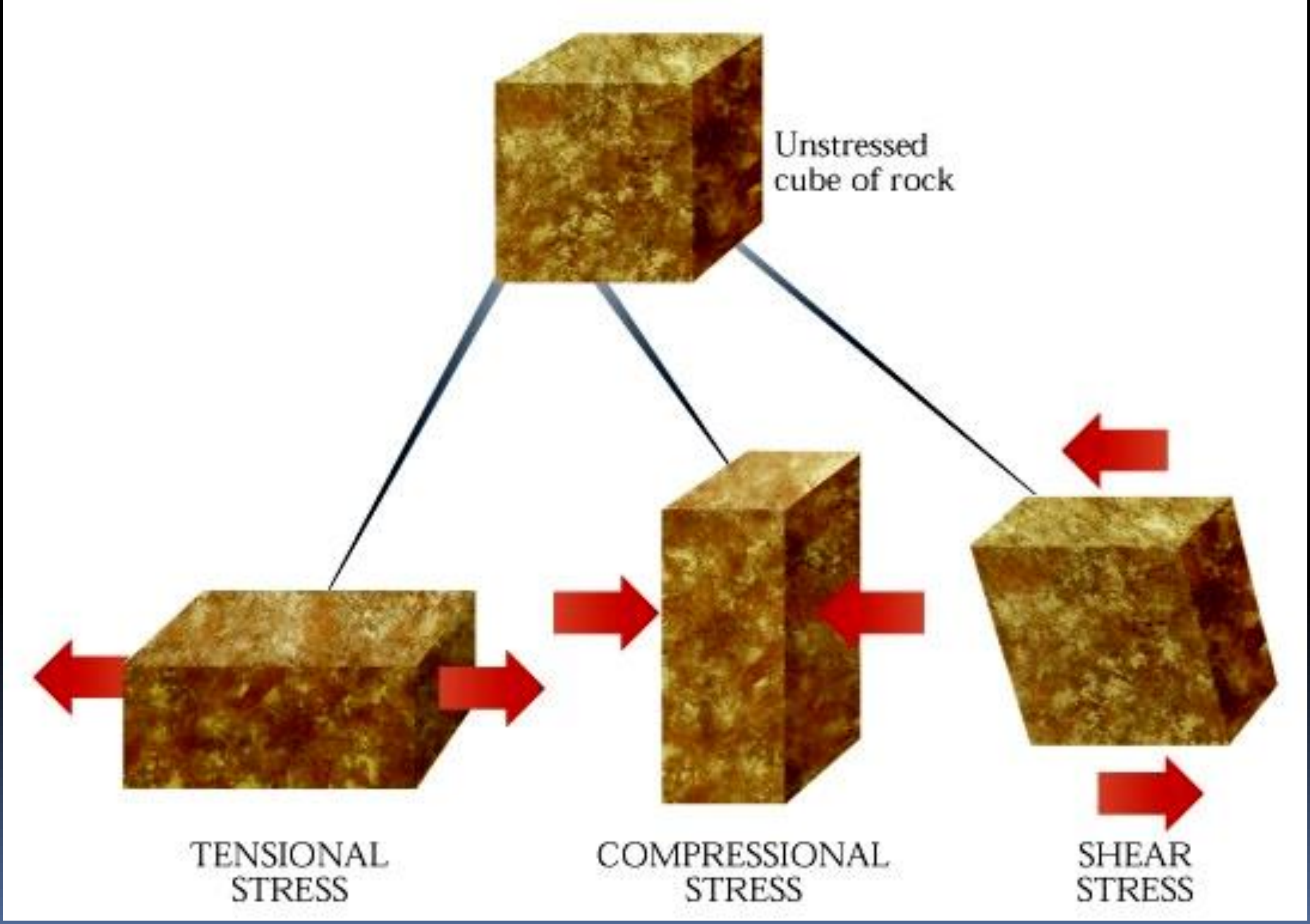


Types of Stress

- Differential stress – force applied is greater in one direction



Types of Differential Stress



Deformation due to Tectonic Forces